US010709206B2

(12) **United States Patent**
Walker et al.

(10) **Patent No.: US 10,709,206 B2**
(45) **Date of Patent: Jul. 14, 2020**

(54) **METHOD OF FILLING ELECTRORHEOLOGICAL FLUID STRUCTURE**

(71) Applicant: **NIKE, Inc.**, Beaverton, OR (US)

(72) Inventors: **Steven H. Walker**, Camas, WA (US); **Chin-yuan Cheng**, Kirkland, WA (US)

(73) Assignee: **NIKE, Inc.**, Beaverton, OR (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 237 days.

(21) Appl. No.: **15/363,436**

(22) Filed: **Nov. 29, 2016**

(65) **Prior Publication Data**

US 2017/0150785 A1 Jun. 1, 2017

Related U.S. Application Data

(60) Provisional application No. 62/260,897, filed on Nov. 30, 2015.

(51) **Int. Cl.**

A43D 63/00	(2006.01)
A43B 13/20	(2006.01)
A43B 13/18	(2006.01)
A43D 999/00	(2006.01)
A43B 3/00	(2006.01)
B65B 31/02	(2006.01)

(52) **U.S. Cl.**

CPC ***A43D 63/00*** (2013.01); ***A43B 3/0005*** (2013.01); ***A43B 13/189*** (2013.01); ***A43B 13/20*** (2013.01); ***A43D 999/00*** (2013.01); ***B65B 31/02*** (2013.01)

(58) **Field of Classification Search**

USPC 219/766

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2,472,754 A * 6/1949 Mead A43B 7/28 206/524.8
4,183,156 A * 1/1980 Rudy A43B 17/035 36/29

(Continued)

FOREIGN PATENT DOCUMENTS

CN 101337593 A 1/2009
CN 101337593 B * 9/2011

(Continued)

OTHER PUBLICATIONS

Mar. 10, 2017—(WO) ISR & WO—App. No. PCT/US16/064085.

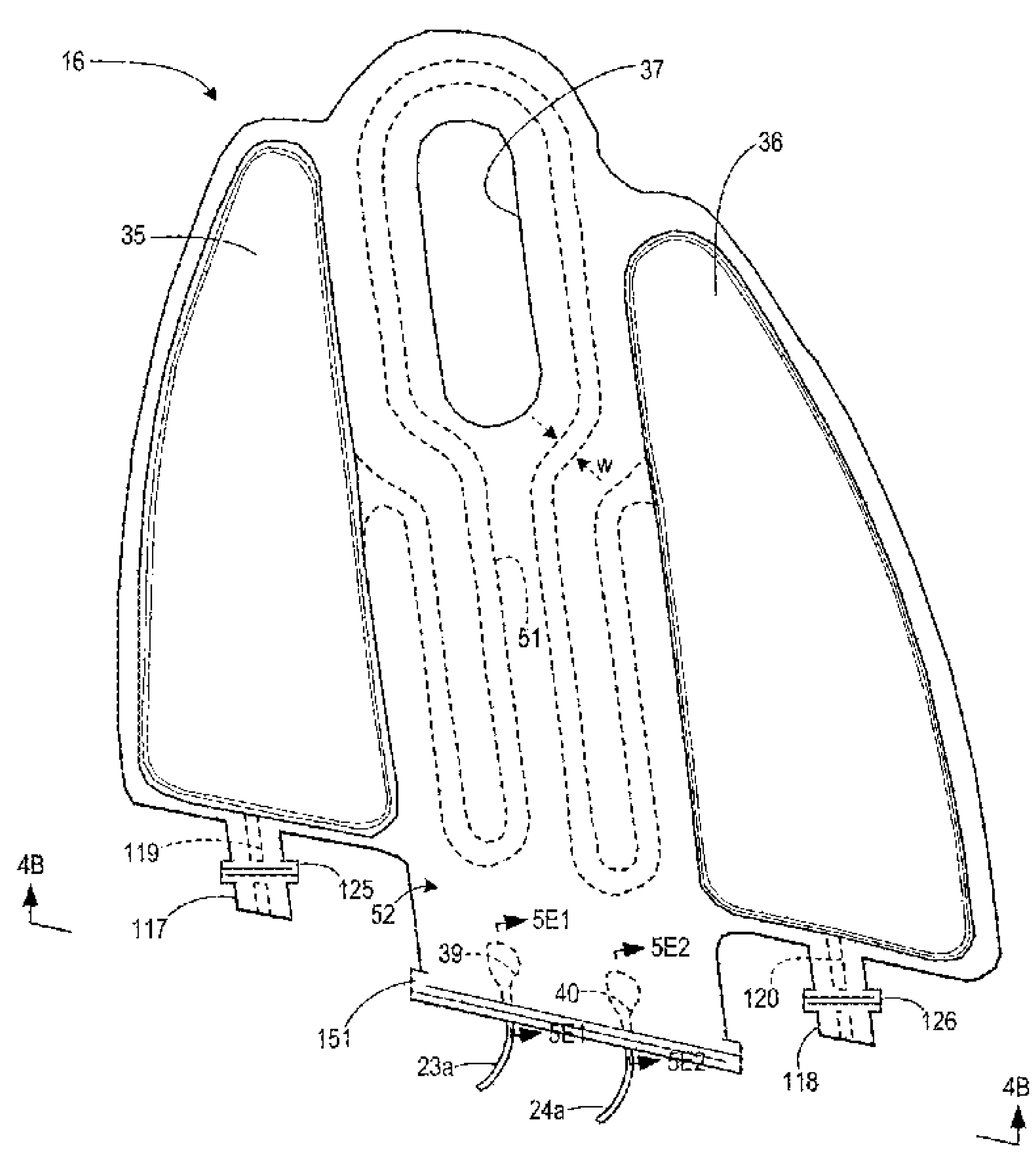
(Continued)

Primary Examiner — Ibrahime A Abraham
Assistant Examiner — Elizabeth M Sims
(74) *Attorney, Agent, or Firm* — Banner & Witcoff, Ltd.

(57) **ABSTRACT**

A housing of an incline adjuster may include a medial fluid chamber in fluid communication with a lateral fluid chamber through a serpentine transfer channel. The housing of the incline adjuster may include channels through which electrorheological fluid may be injected into the chambers. A method of filling an electrorheological fluid structure may include introducing electrorheological fluid into an interior volume of a housing. The electrorheological fluid within the housing may then be subjected to a sub-atmospheric pressure. Subsequently, the interior volume may be sealed relative to an exterior of the housing.

12 Claims, 27 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

4,864,738	A *	9/1989	Horovitz	A43B 13/20 36/29
5,240,477	A	8/1993	Yamaga et al.	
5,335,486	A *	8/1994	Davis	B65B 3/02 53/374.8
5,788,078	A *	8/1998	Fuss	B65B 9/15 206/521
6,277,306	B1	8/2001	Endo et al.	
6,378,558	B1 *	4/2002	Pohl	F16F 9/34 137/807
6,725,888	B1 *	4/2004	Richter	B65B 3/18 141/114
6,837,919	B2 *	1/2005	Asako	B01D 19/0036 188/267.1
7,093,710	B2 *	8/2006	Shimizu	B41J 2/17533 206/213.1
7,156,201	B2	1/2007	Peshkovskiy et al.	
7,409,779	B2 *	8/2008	Dojan	A43B 7/144 36/29
8,651,230	B2	2/2014	Peshkovsky et al.	
9,142,751	B2	9/2015	Peshkovsky et al.	
2002/0053146	A1 *	5/2002	Swigart	A43B 13/203 36/29
2006/0059714	A1 *	3/2006	Harmon-Weiss	A43B 13/20 36/35 B
2006/0157888	A1 *	7/2006	Mata Diego	A43B 7/28 264/223
2006/0230636	A1 *	10/2006	Kokstis	A43B 1/0009 36/35 B
2006/0248750	A1 *	11/2006	Rosenberg	A43B 1/0054 36/29
2008/0138774	A1 *	6/2008	Ahn	G09B 21/004 434/114
2012/0138631	A1 *	6/2012	Lurcott	B01F 3/0861 222/1
2012/0233880	A1 *	9/2012	Chao	A43B 13/20 36/29
2012/0255198	A1 *	10/2012	Langvin	A43B 7/144 36/29
2014/0020264	A1 *	1/2014	Holt	A43B 13/189 36/103
2014/0173937	A1 *	6/2014	Smith	A43B 13/189 36/102
2014/0277632	A1 *	9/2014	Walker	G01L 1/2206 700/91

FOREIGN PATENT DOCUMENTS

CN	101337593	B *	9/2011
GB	2318529	A	4/1998
JP	S52115803	A	9/1977
JP	S6393311	A	4/1988
JP	H05112793	A	5/1993
JP	2004195982	A	7/2004
KR	101311156	B1 *	9/2013

OTHER PUBLICATIONS

Suzuki, et al., Bubble Elimination for Coating Material, [retrieved on Aug. 24, 2017]. Retrieved from the Internet <URL:*>http://www.opussystem.com/puki/index.php?plugin=attach&refer=opussystem%2F catalogue_jp&openfile=%2701%20TAPPI.pdf.

Suzuki, et al., Visualization and Analysis of Swirling Flow in Bubble Eliminator, [retrieved on Aug. 2017, [retrieved on Aug. 17, 2017]. Retrieved from the Internet <URL:*>http://www.opussystem.com/puki/index.php?plugin=attach&refer=opussystem%2Fcatalogue_jp&openfile=%2702%20IFPE%20%20%282%29.pdf.

Tanaka et al., Experimental and Numerical Investigation of Active Heat Exchange for Fluid Power Systems. 7th International Symposium on Fluid Control, Measurement and Visualization, [retrieved on Aug. 24, 2017]. Retrieved from the Internet <URL:*>http://www.opussystem.com/puki/index.php?plugin=attach&refer=opussystem%2Fcatalogue_jp&openfile=%2703%20FLCOME.pdf.

Suzuki, et al., Bubble Elimination in Hydraulic Fluids: Part 1—Basic Principle and Technology Overview, [retrieved on Aug. 24, 2017]. Retrieved from the Internet <URL:*>http://www.opussystem.com/puki/index.php?plugin=attach&refer=opussytem%2Fcatalogue_jp&openfile=$2705%20IFPE%20%281%29.pdf.

Suzuki, et al., Downsizing of Oil Reservoir by Bubble Eliminator, [retrieved on Aug. 24, 2017]. Retrieved from the Internet <URL:*>http://www.opussystem.com/puki/index.php?plugin=attach&refer=opussytem%2Fcatalogue_jp&openfile=%2705%20JFPS%20%281%29.pdf.

Nagashi, et al., Bubble Elimination for Hydraulic Systems, [retrieved on Aug. 24, 2017]. Retrieved from the Internet <URL:*>http://www.opussystem.com/puki/index.php?plugin=attach&refer=opussytem%2Fcatalogue_jp&openfile=%2708$20FPNI-PHD%20Symposium.pdf.

Suzuki, et al., Bubble Elimination Device in Hydraulic Systems, [retrieved Aug. 24, 2017]. Retrieved from the Internet <URL:*>http://www.opussystem.com/puki/index.php?plugin=attach&refer=opussytem%2Fcatalogue_jp&openfile=%279%20ASME.pdf.

Sakama, et al., Optimal Design of Bubble Eliminator by Numerical and Experimental Investigation. Proceedings of the 8th JFPS International Symposium on Fluid Power, Okinawa 2011, Oct. 25-28, 2011, [retrieved Aug. 24, 2017]. Retrieved from the Internet <URL:*>http://www.jfps.jp/proceedings/okinawa2011/pdf/1C1-2.pdf.

Bubble-Less Eliminator, Bubble Removal Device Catalog, [retrieved Aug. 24, 2017]. Retrieved from the Internet <URL:*>http://www.getottenassociates.com/pdf_files/Bubble%20Eliminator%20Catalog.pdf.

Tanaka, et al., Operation and Typical Application Overview of the Use of Bubble Eliminators for De-aeration of Hydraulic and Turbine Oils, [retrieved Aug. 24, 2017]. Retrieved from the Internet <URL:*>http://www.getottenassociates.com/pdf_files/Bubble%20Eliminator%20Paper%20for%20FP%20Expo%202003.pdf.

Ultrasonic Transducers, Sono Mechanics, [retrieved prior to Aug. 21, 2017]. Retrieved from the Internet <URL:*>http://www.sonomechanics.com.

Ultrasonic Horn Designs and Properties, Sono Mechanics, [retrieved prior to Aug. 21, 2017]. Retrieved from the Internet <URL:*>http://www.sonomechanics.com.

User Manual, ISP-3000 Industrial-Scale Ultrasonic Liquid Processor, [retrieved prior to Aug. 21, 2017]. Retrieved from the Internet <URL:*>http://www.sonomechanics.com.

Sonomechanics Blog (Removing Air from Oils, Epoxies, Hydraulic Fluids, Adhesives, waxes and Other Liquids) [online], Mar. 2016 [retrieved Aug. 24, 2017]. Retrieved from the Internet <URL:*>http://blog.sonomechanics.com/blog/ultrasonic-degassing-of-viscous-liquids.

Suzuki, et al., Bubble Elimination for Efficiency through Fluid Power, [retrieved Aug. 24, 2017]. Retrieved from the Internet <URL:*>http:www.opussystem.com/puki/index.php?plugin=attach&refer=oppussystem%2Fcatalogue_jp&openfile=The%207th%20IFK%202010%20Paper.pdf.

Nov. 23, 2018—(WO) ISR & WO—App. No. PCT/US18/048715.

* cited by examiner

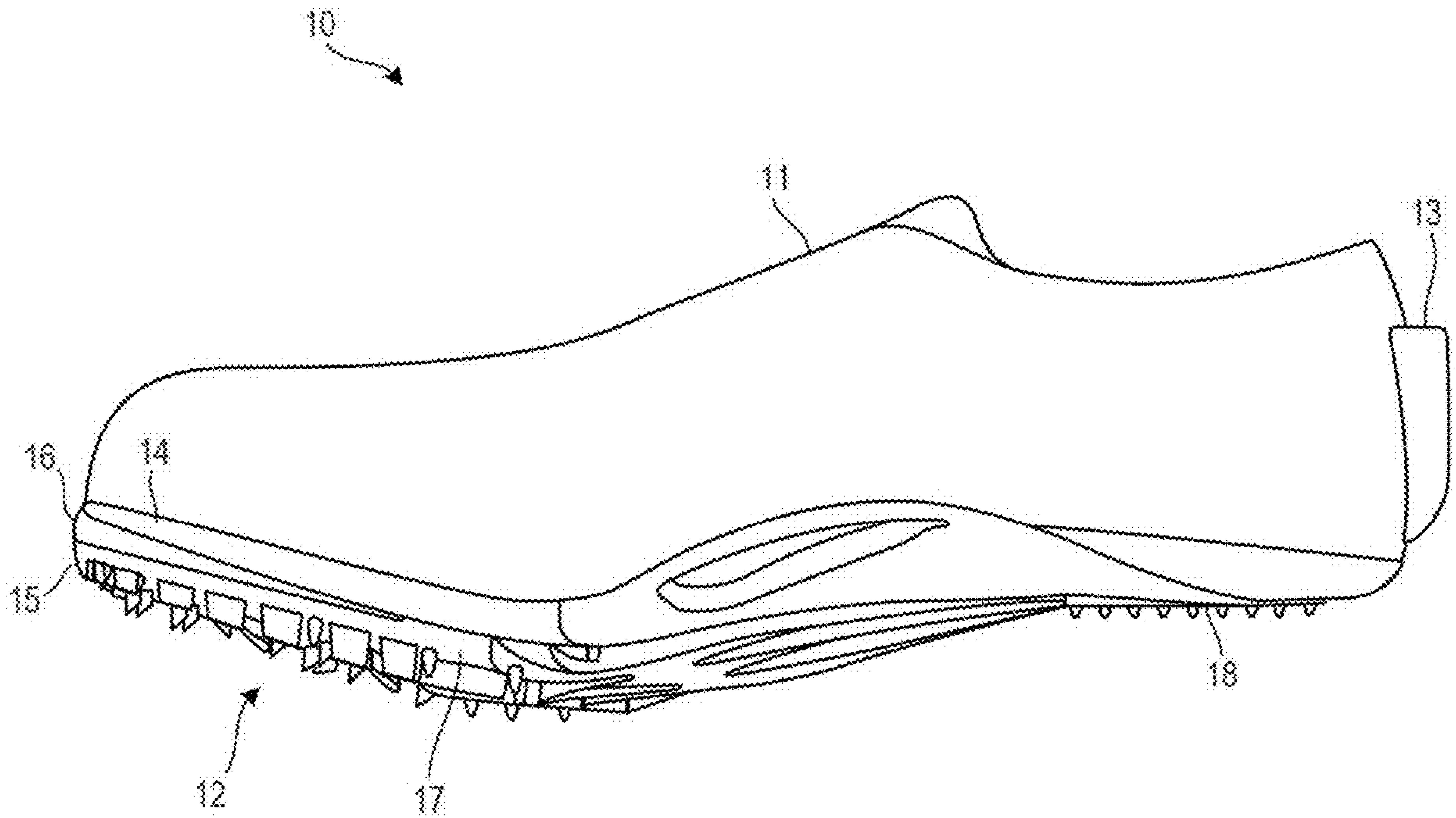


FIG. 1

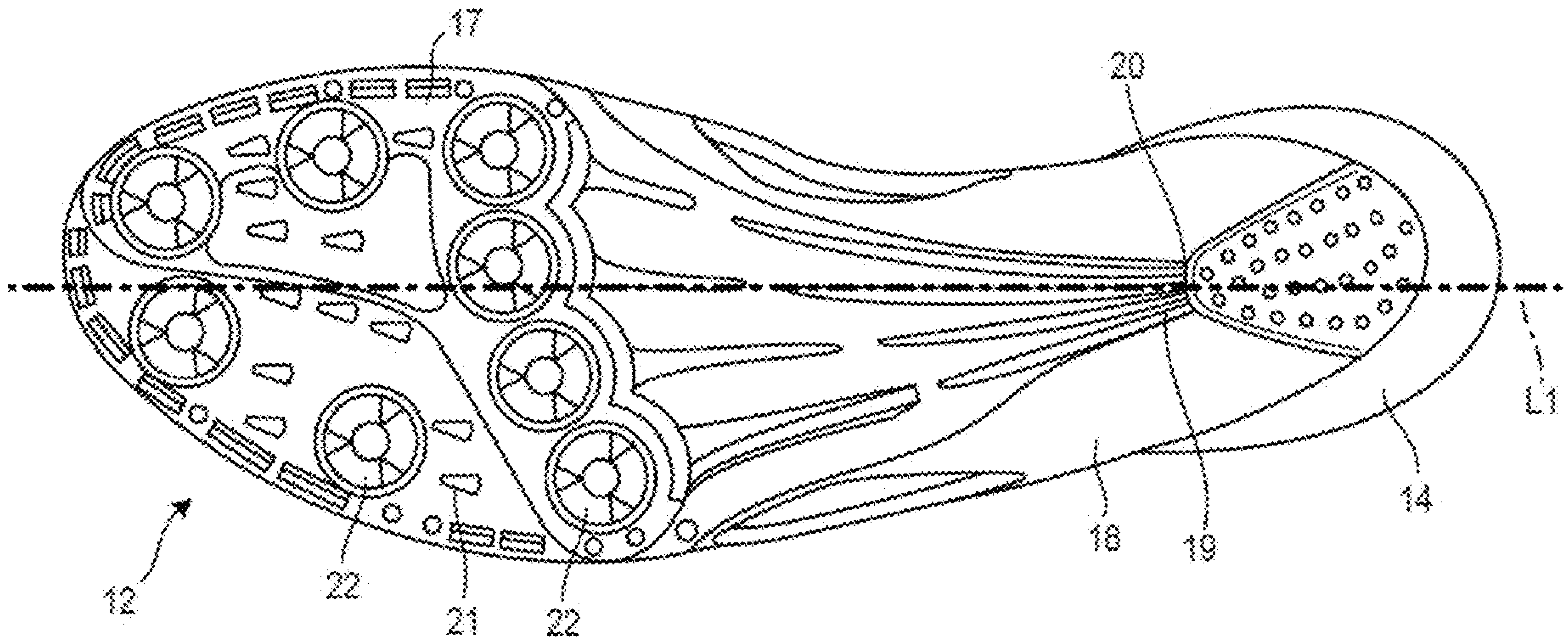


FIG. 2A

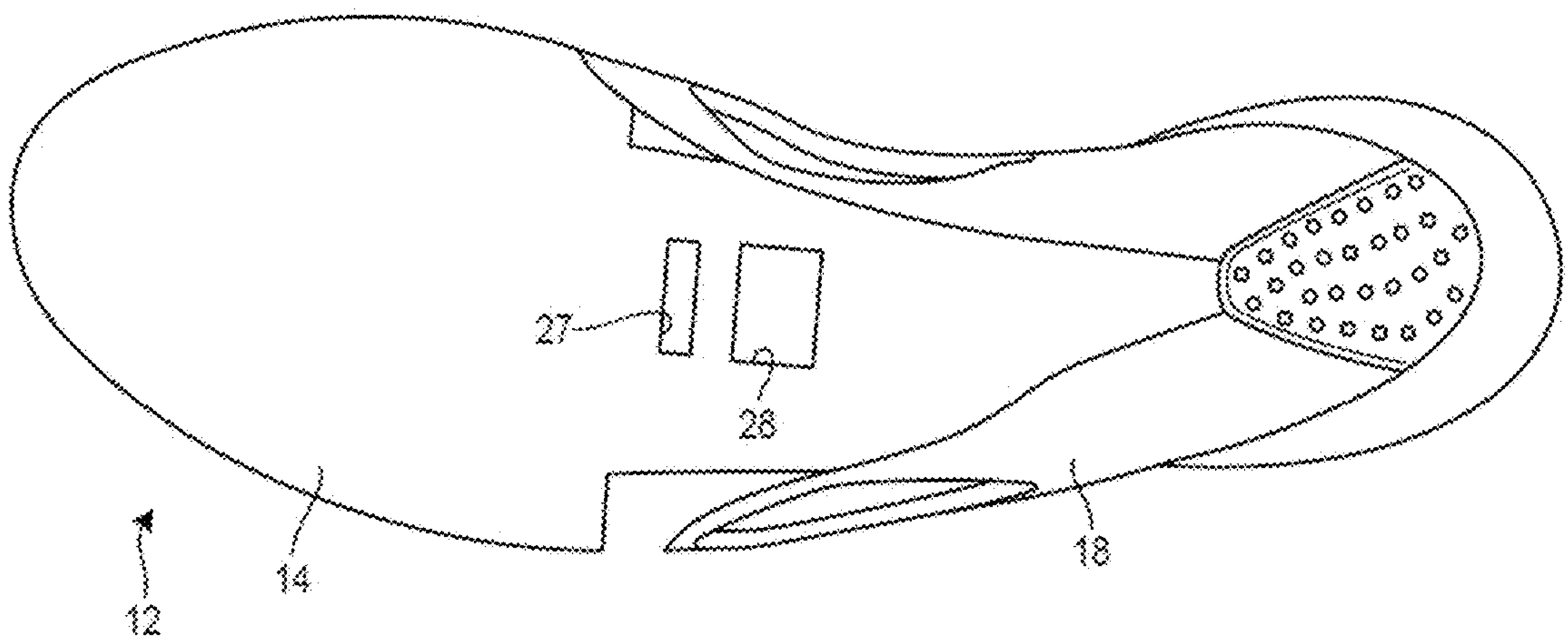


FIG. 2B

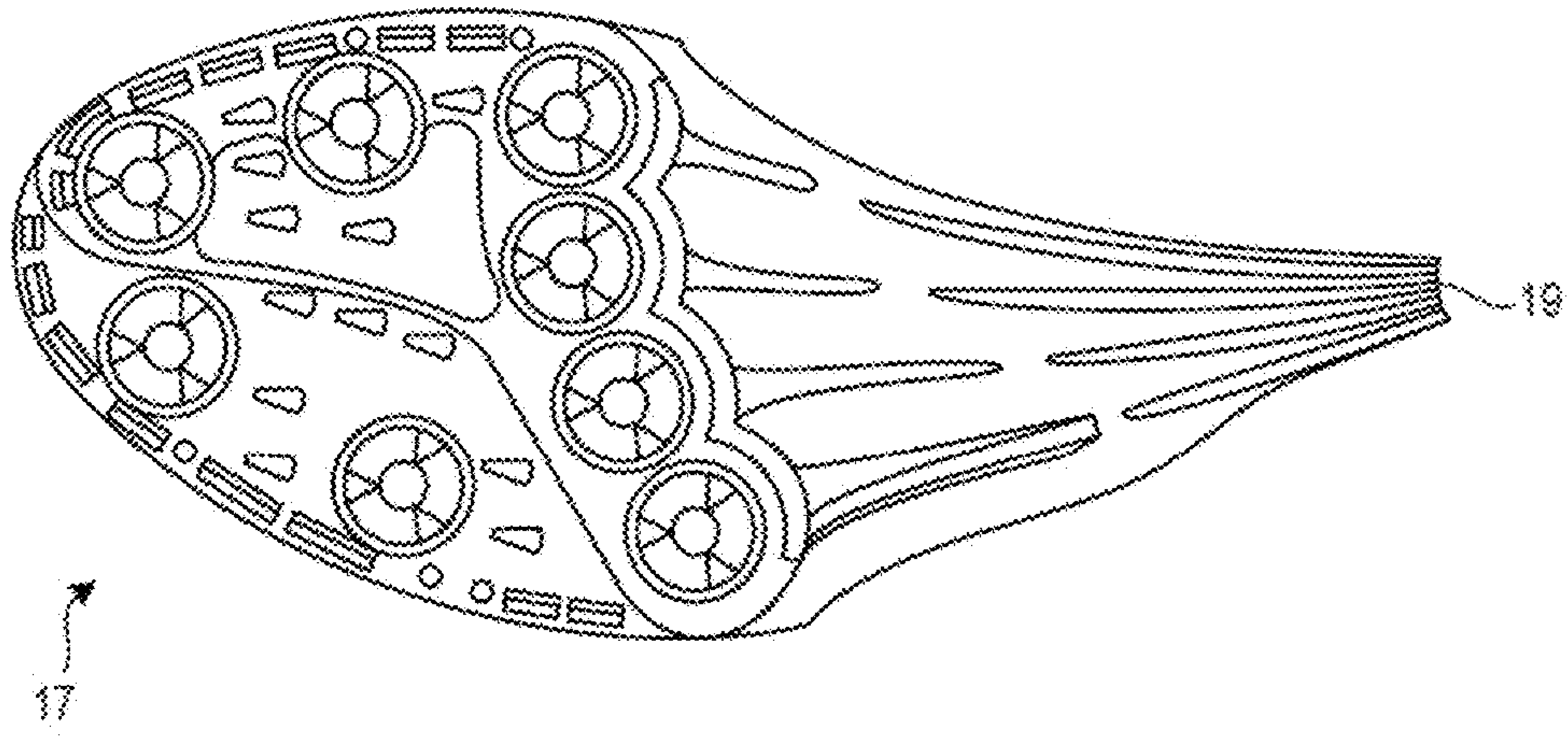


FIG. 2C

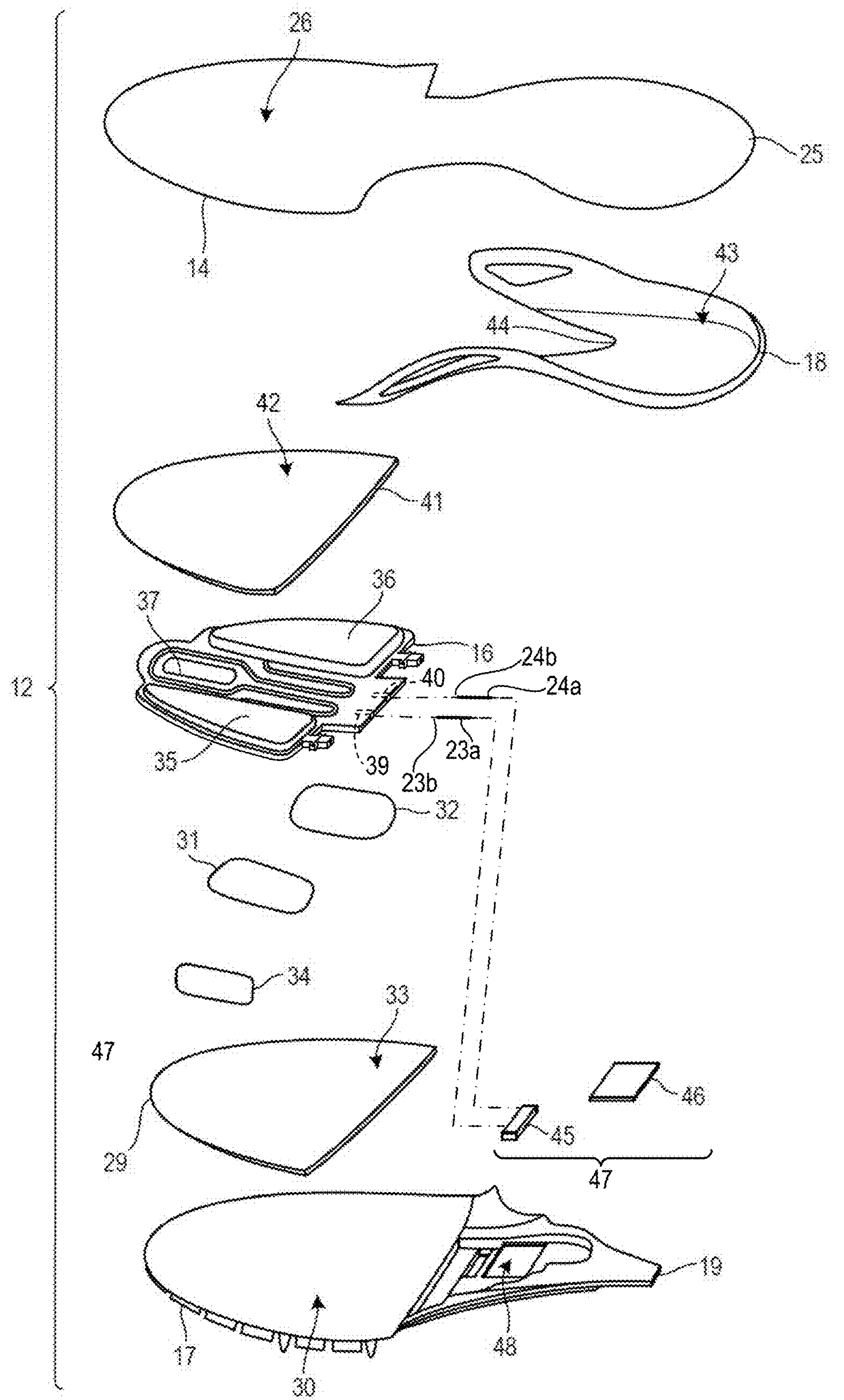

26
25
14
43
44
18
42
41
36
37
16
24b
40
24a
12
35
39
23a
23b
32
31
34
33
47
46
29
45
47
19
48
17
30

FIG. 3

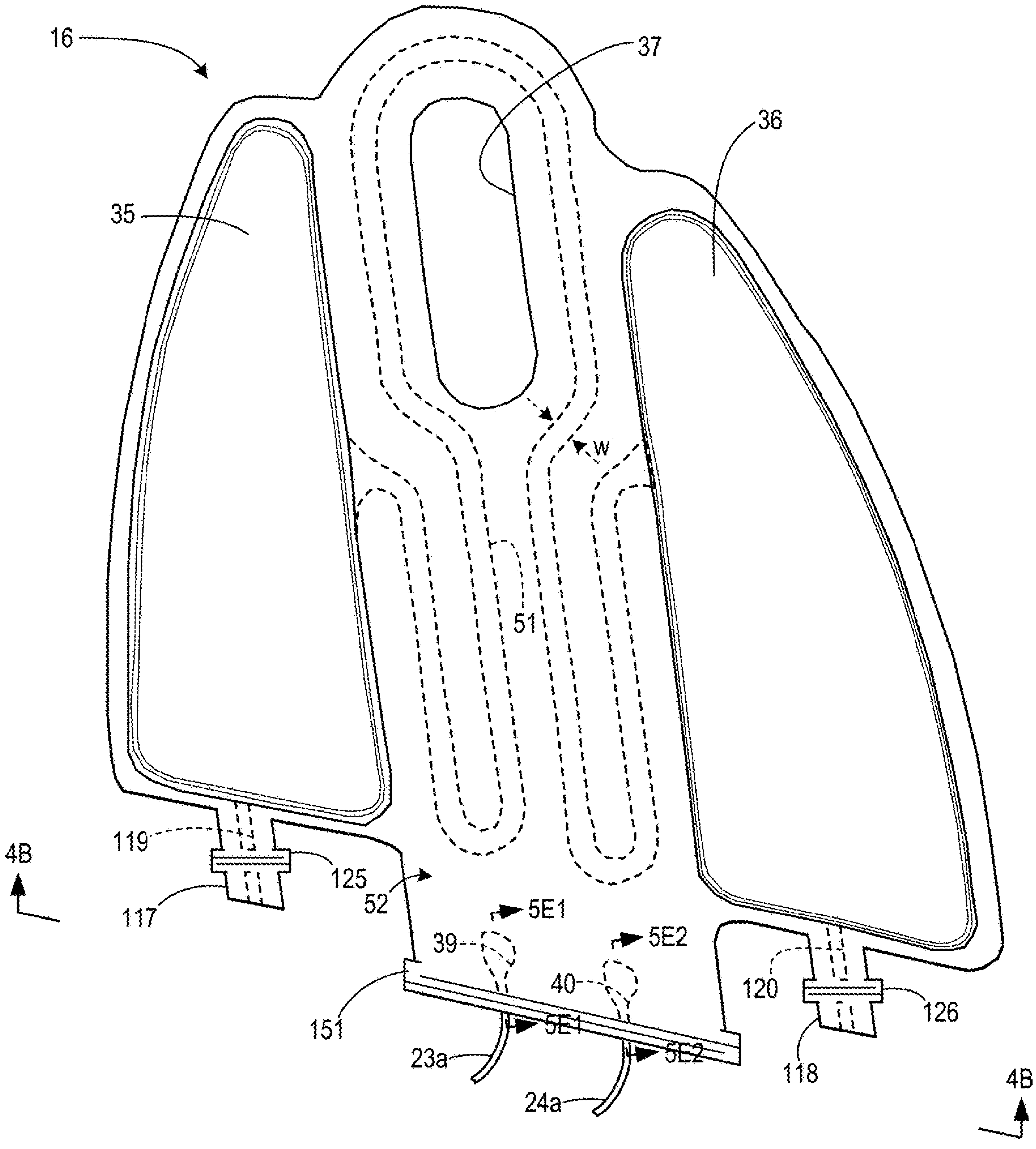

16
37
36
35
51
w
4B
119
125
117
52
5E1
39
5E2
40
120
126
151
5E1
23a
5E2
118
24a
4B

FIG. 4A

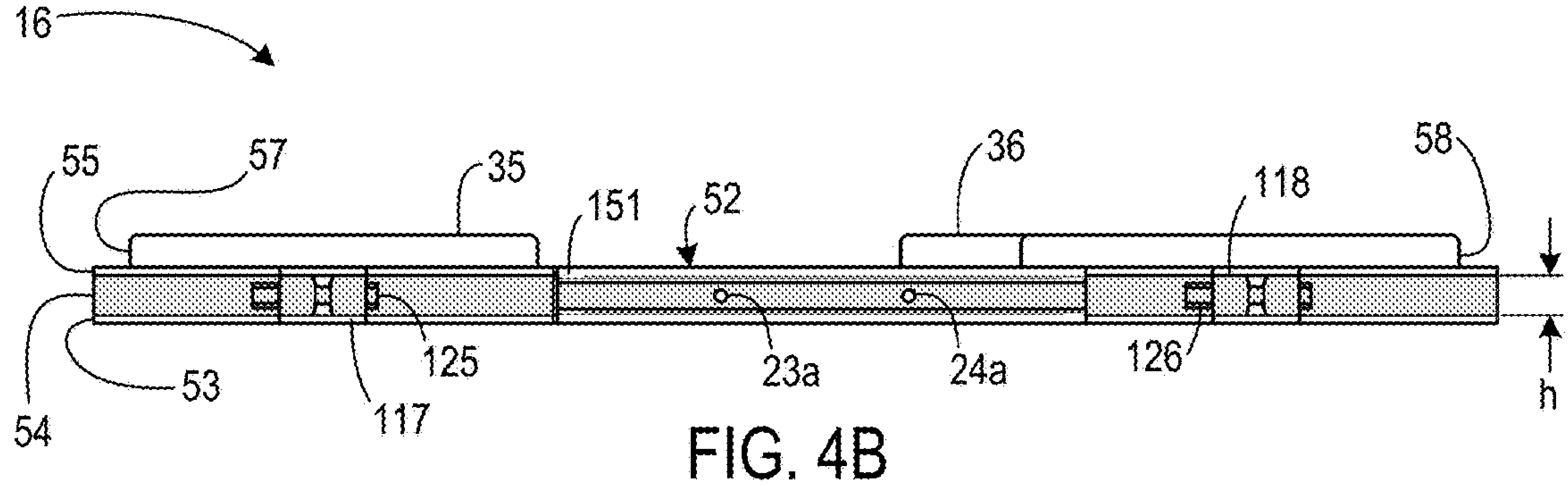

16
55
57
35
151
52
36
118
58
125
23a
24a
126
53
54
117
h

FIG. 4B

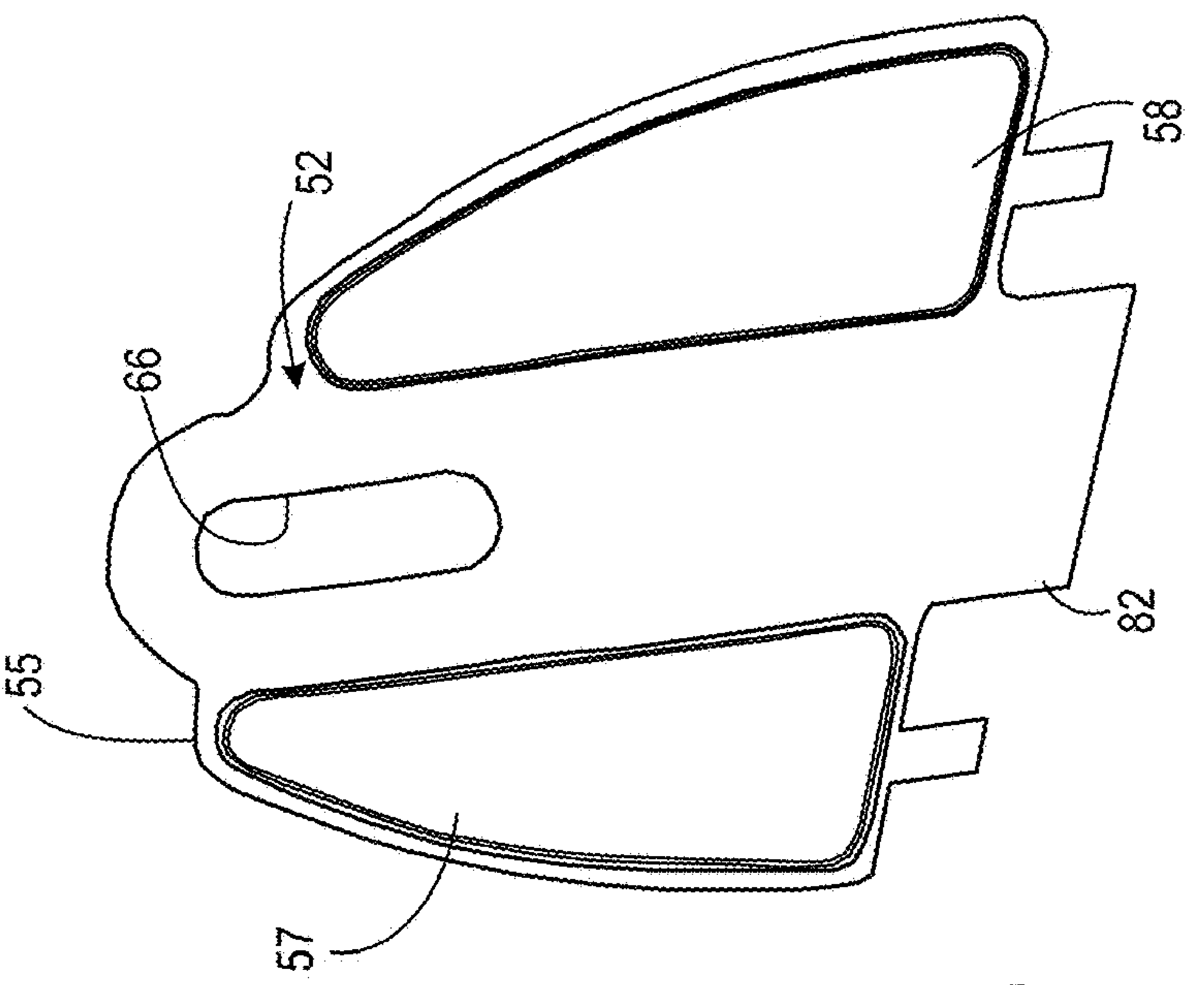


FIG. 5C1

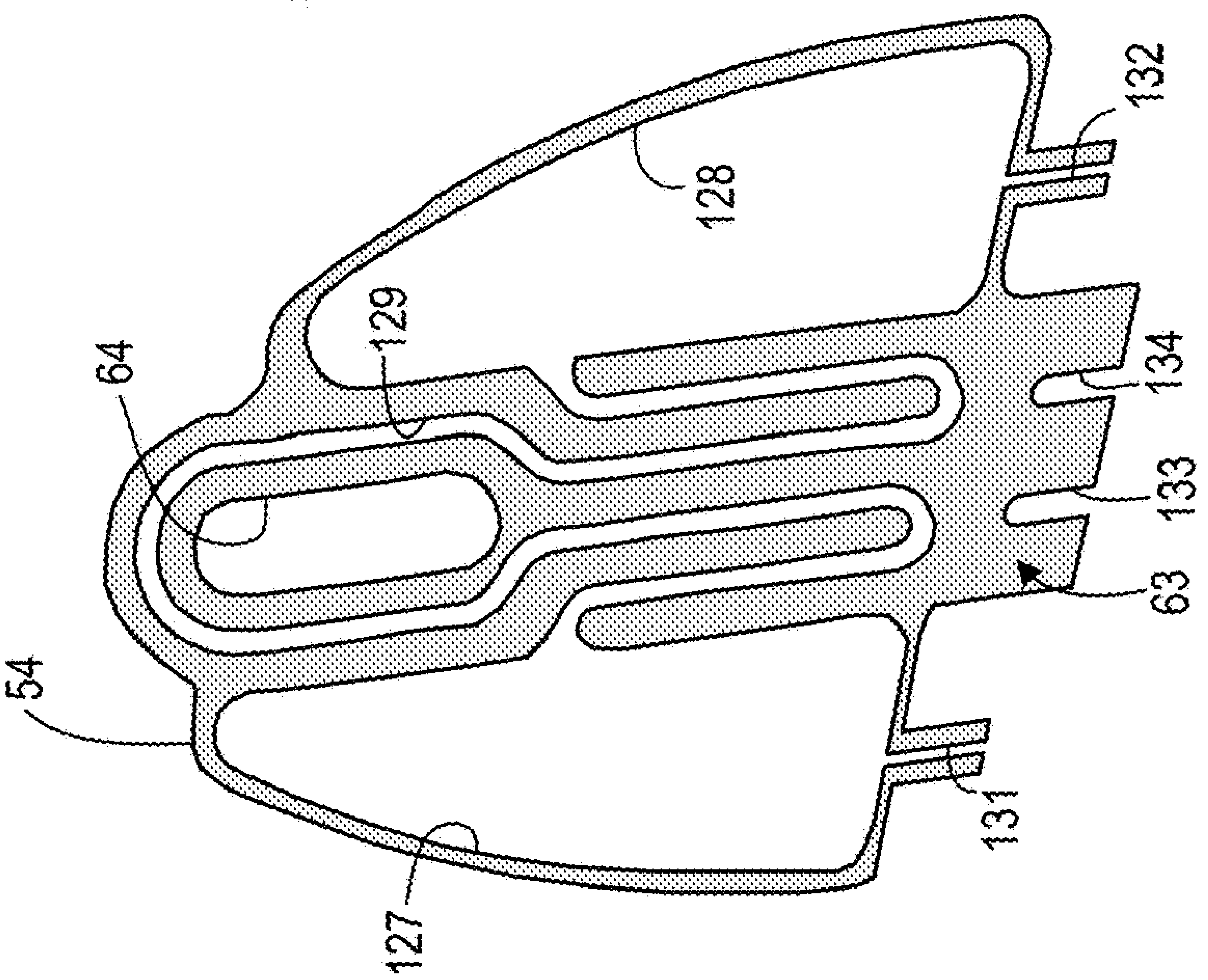


FIG. 5B

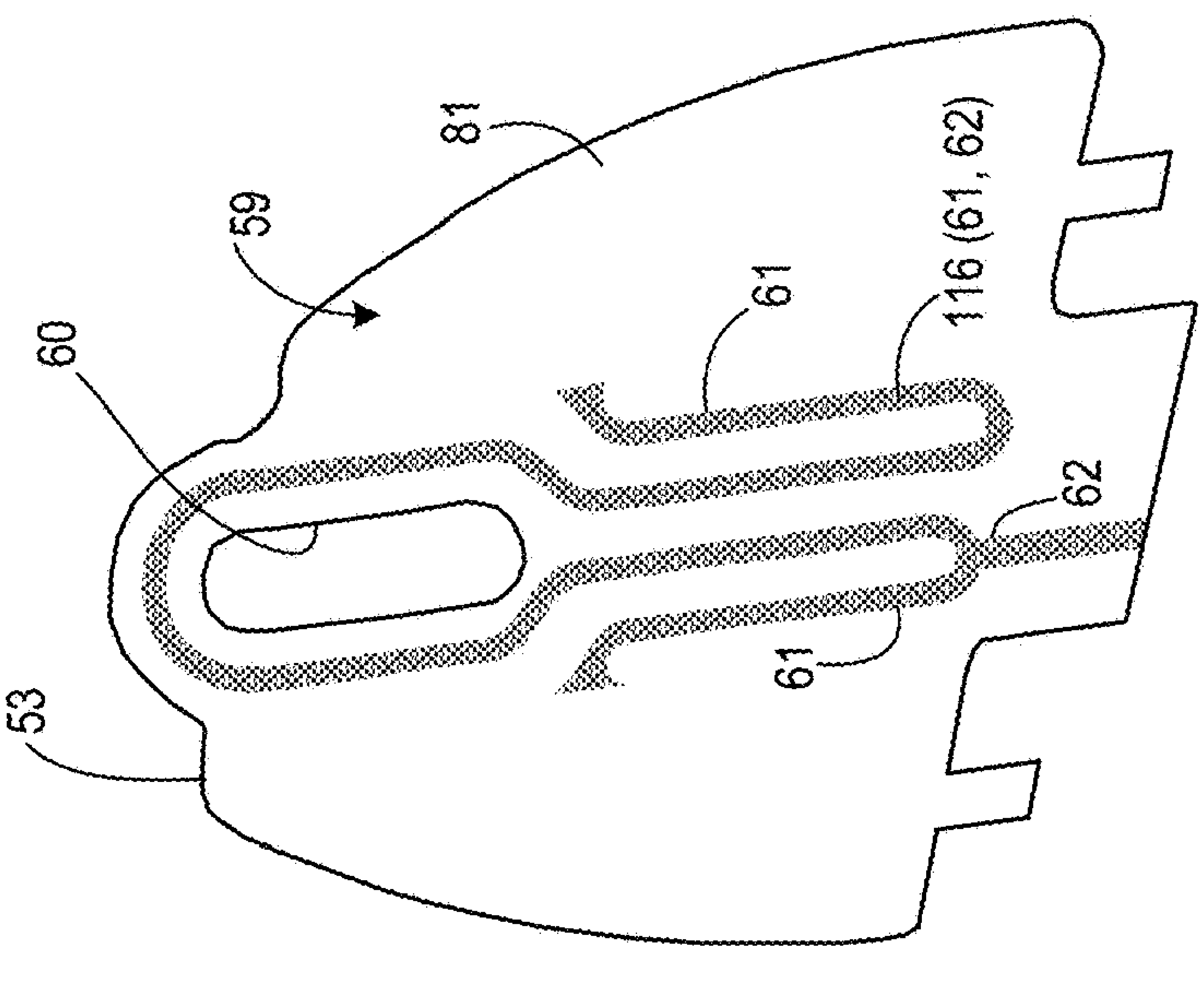


FIG. 5A

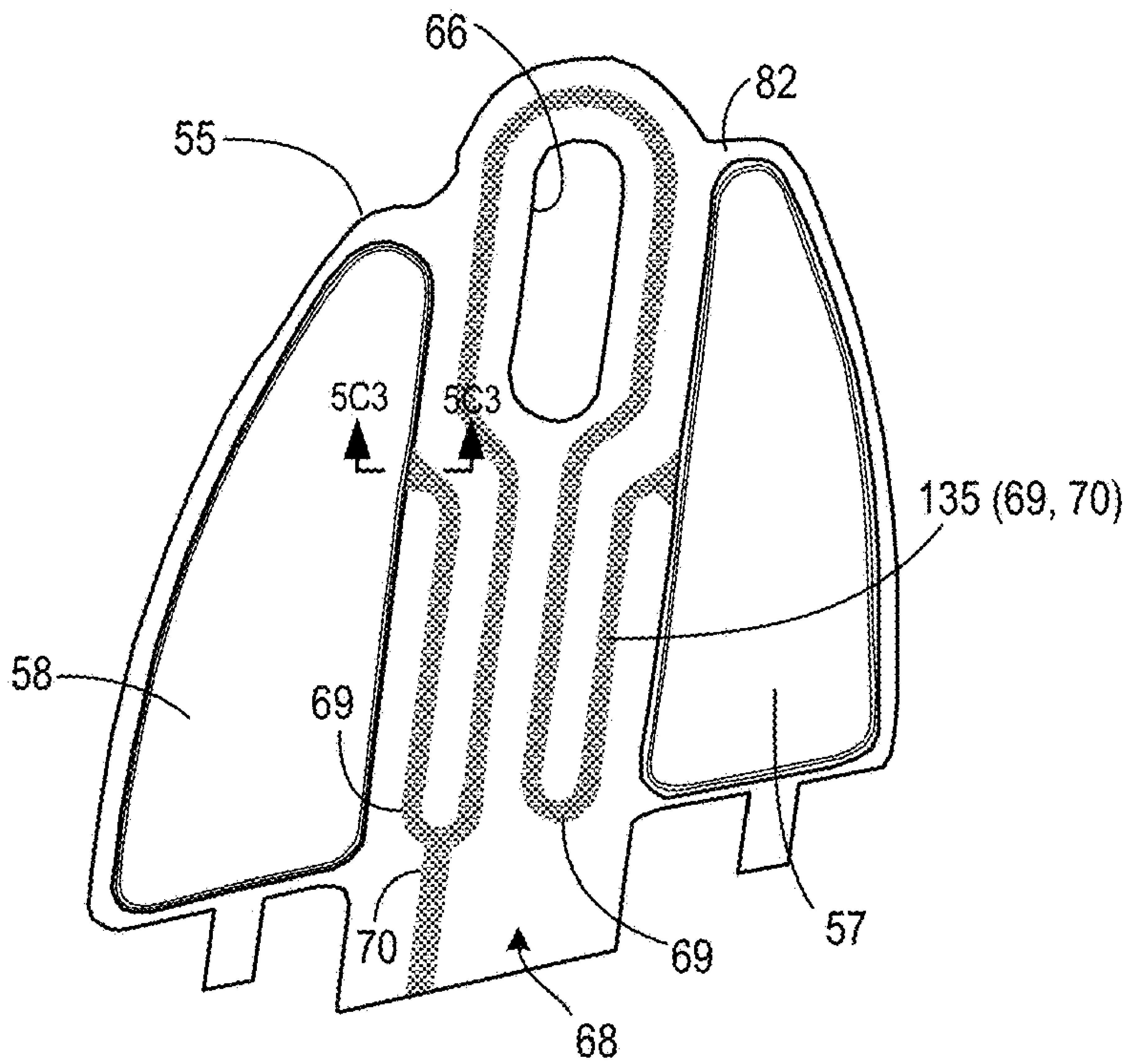


FIG. 5C2

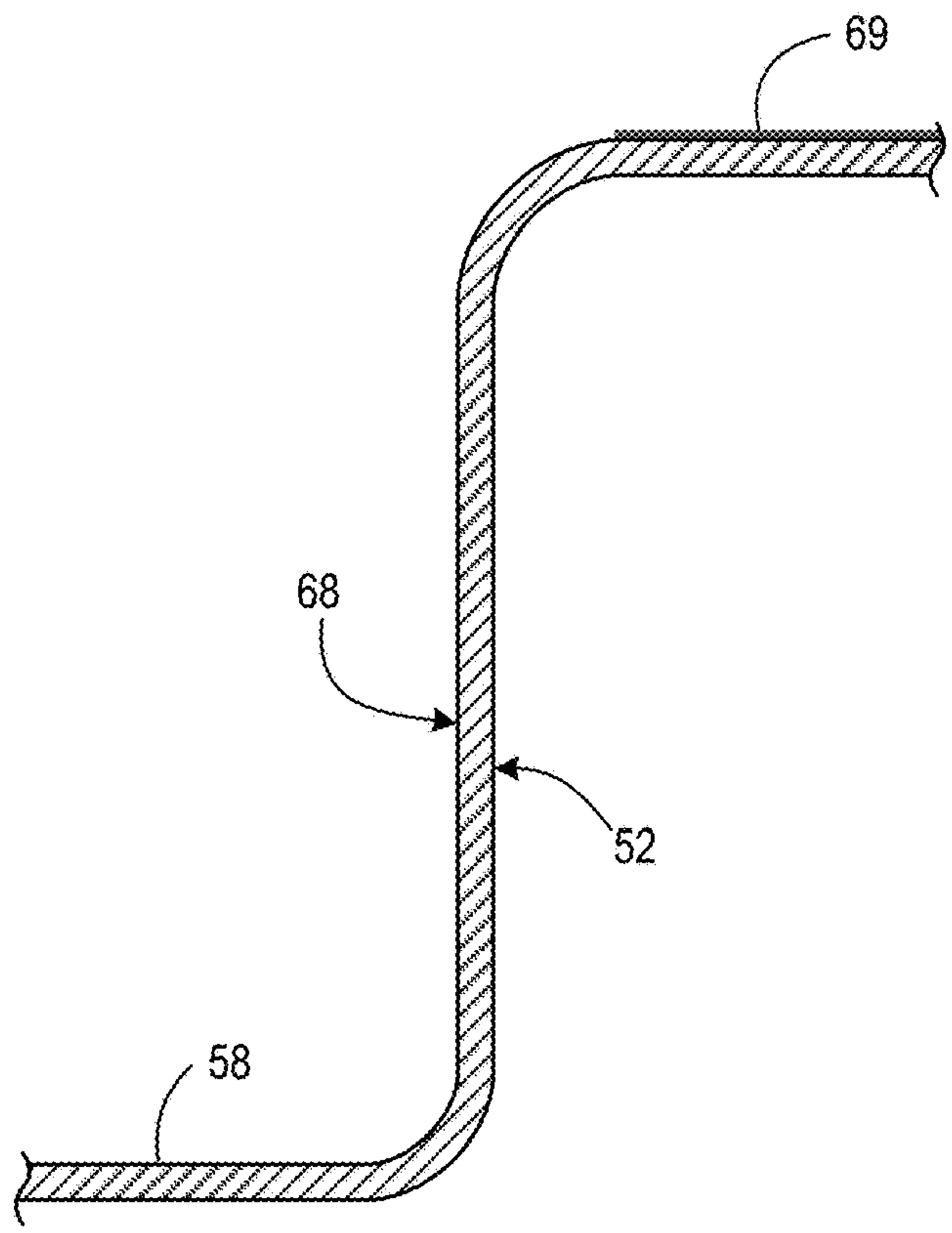


FIG. 5C3

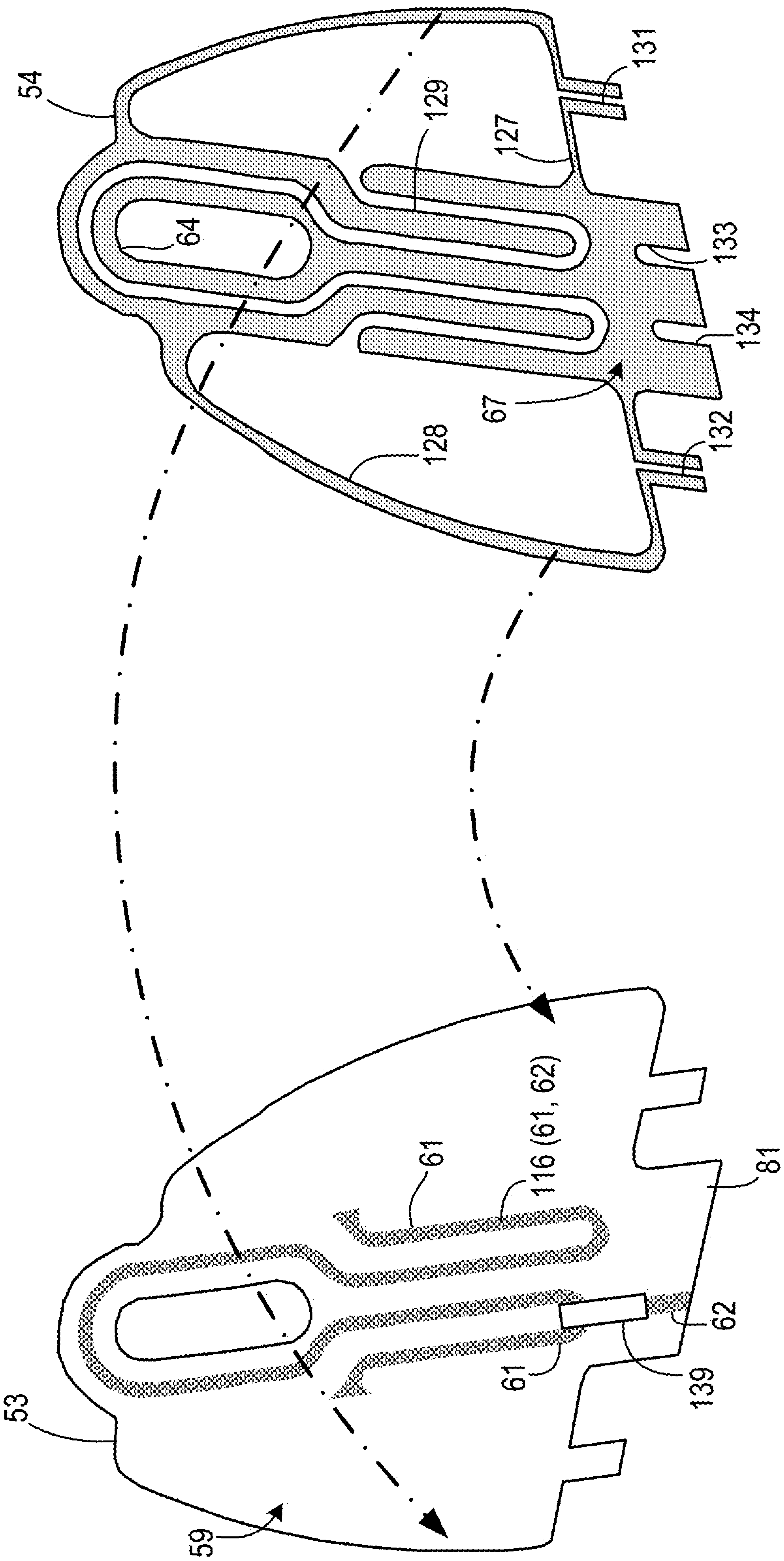


FIG. 5D1

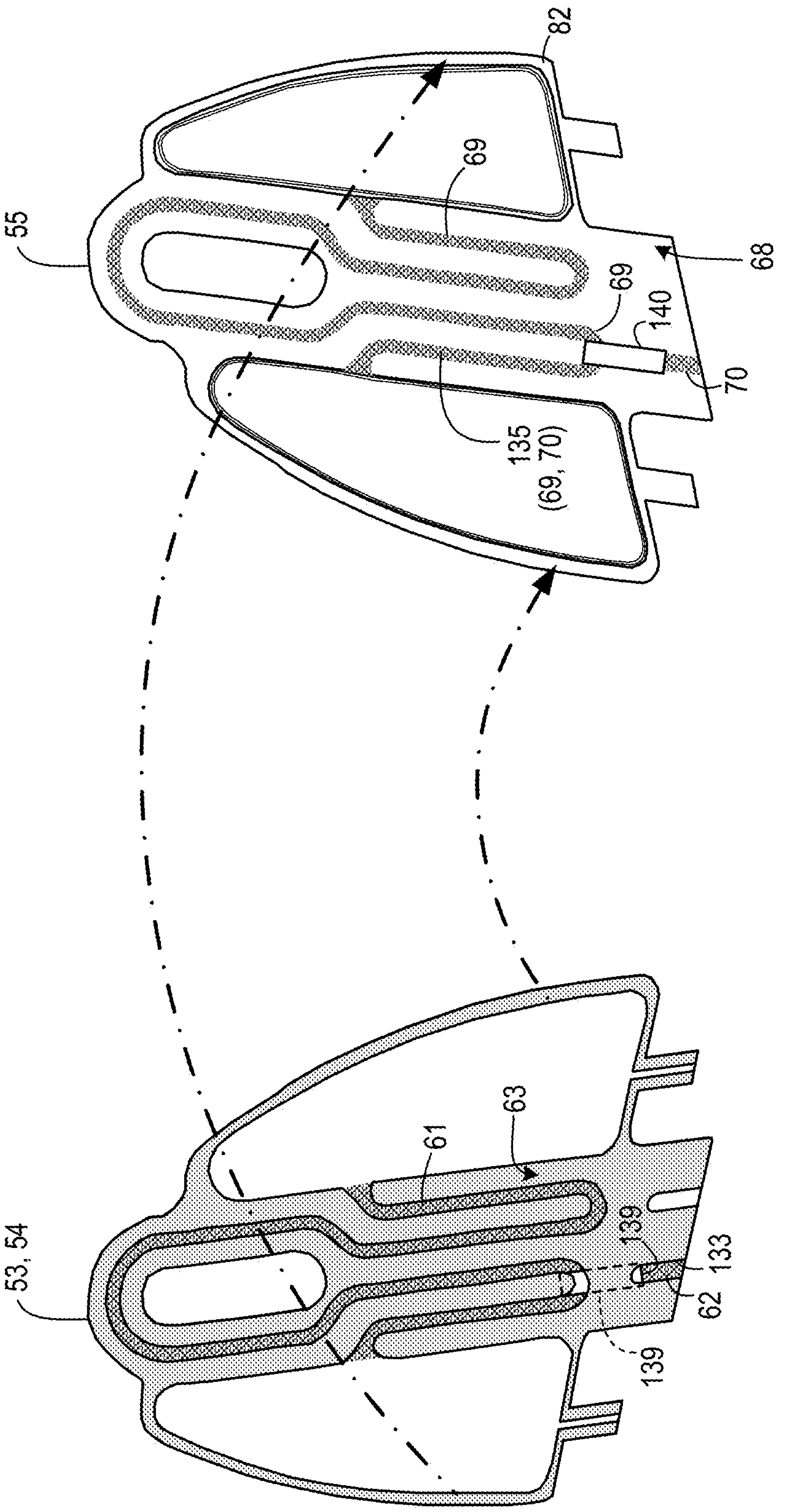


FIG. 5D2

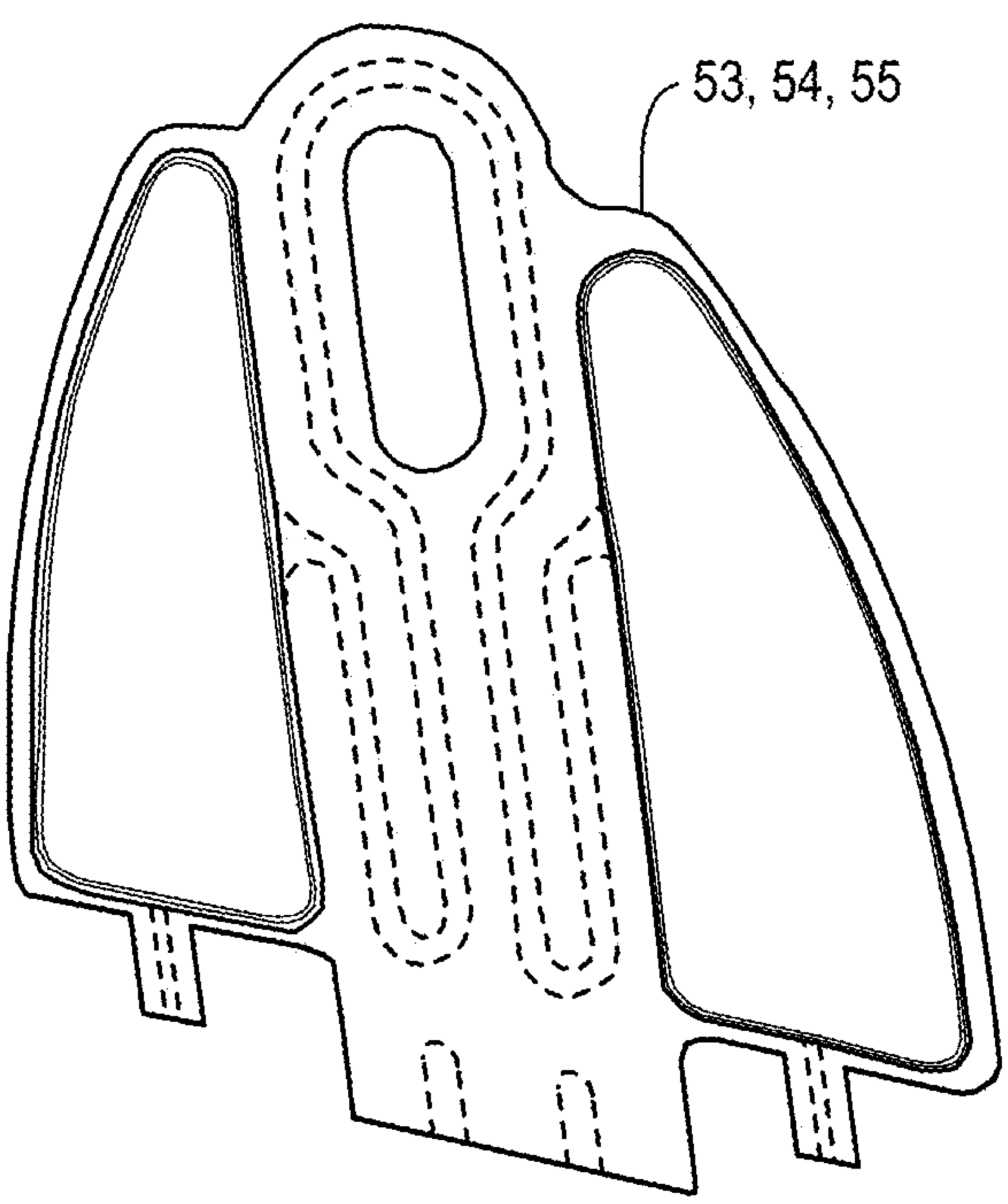
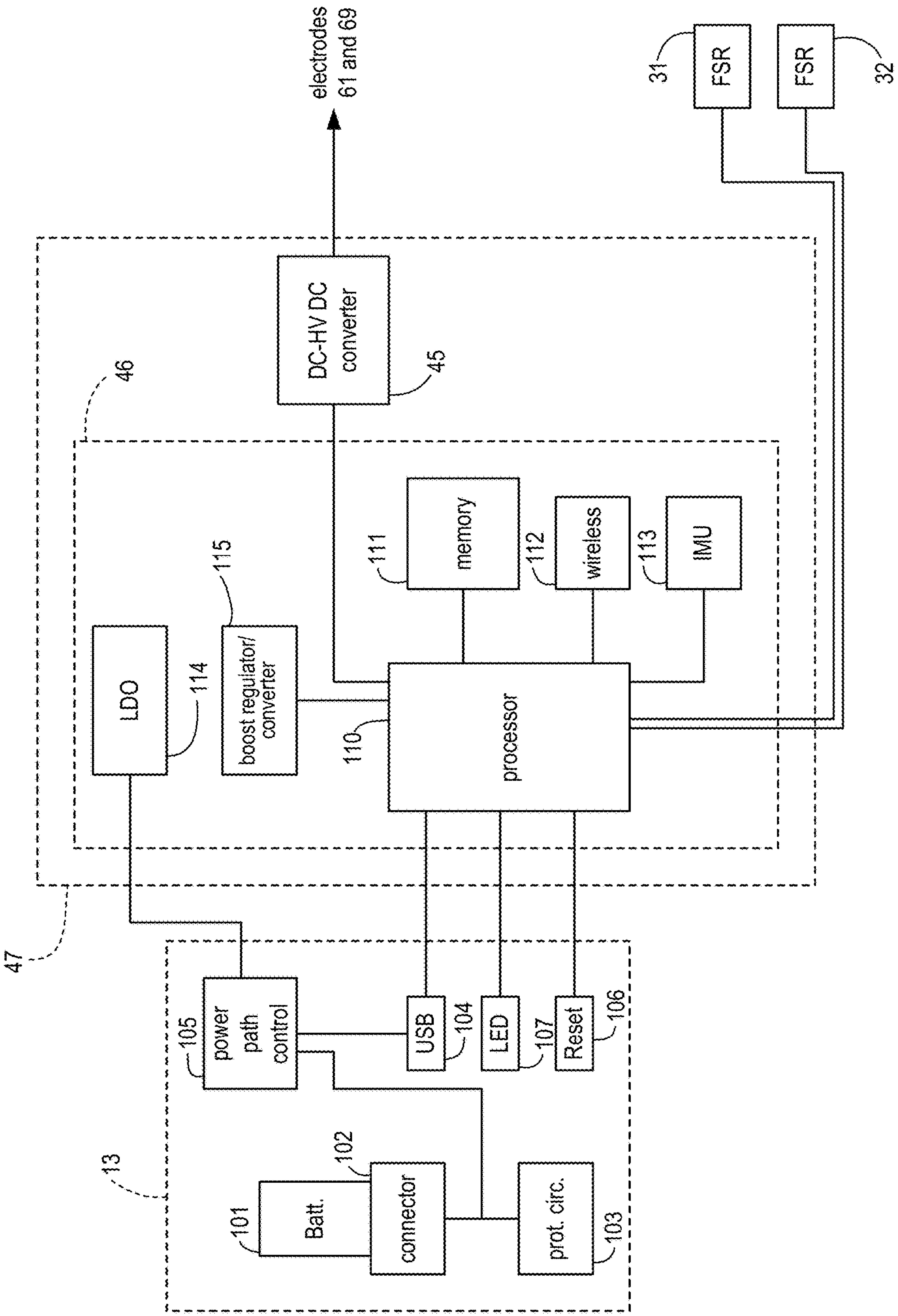


FIG. 5D3



electrodes 61 and 69
FSR
FSR
31
32
DC-HV DC converter
45
46
memory
wireless
IMU
111
112
113
115
boost regulator/ converter
LDO
114
110
processor
47
13
power path control
105
USB
104
LED
107
Reset
106
102
Batt.
101
connector
prot. circ.
103

FIG. 6

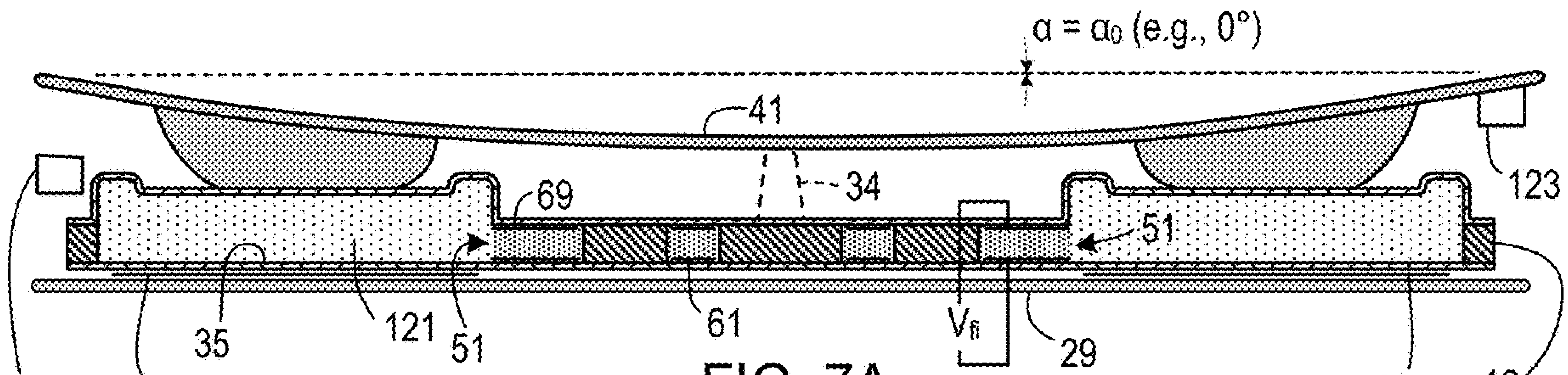


FIG. 7A

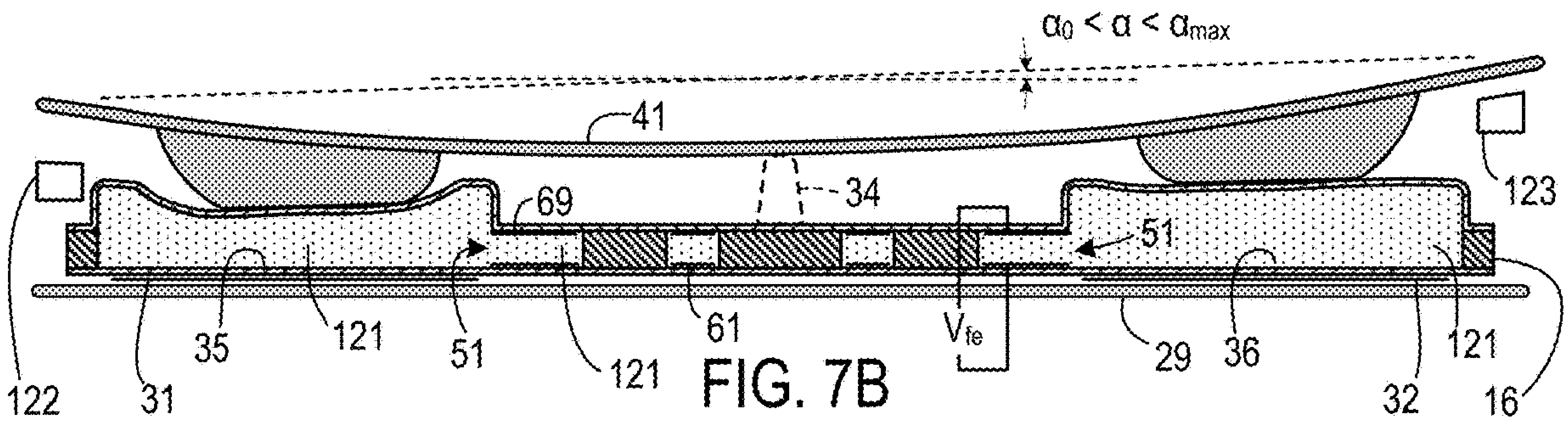


FIG. 7B

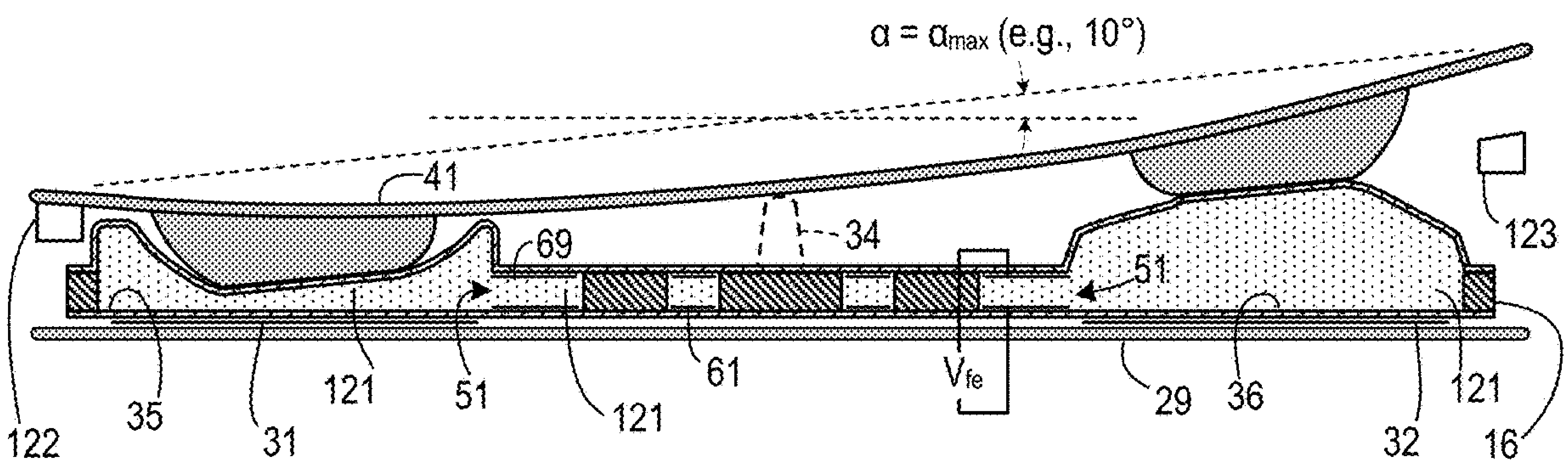


FIG. 7C

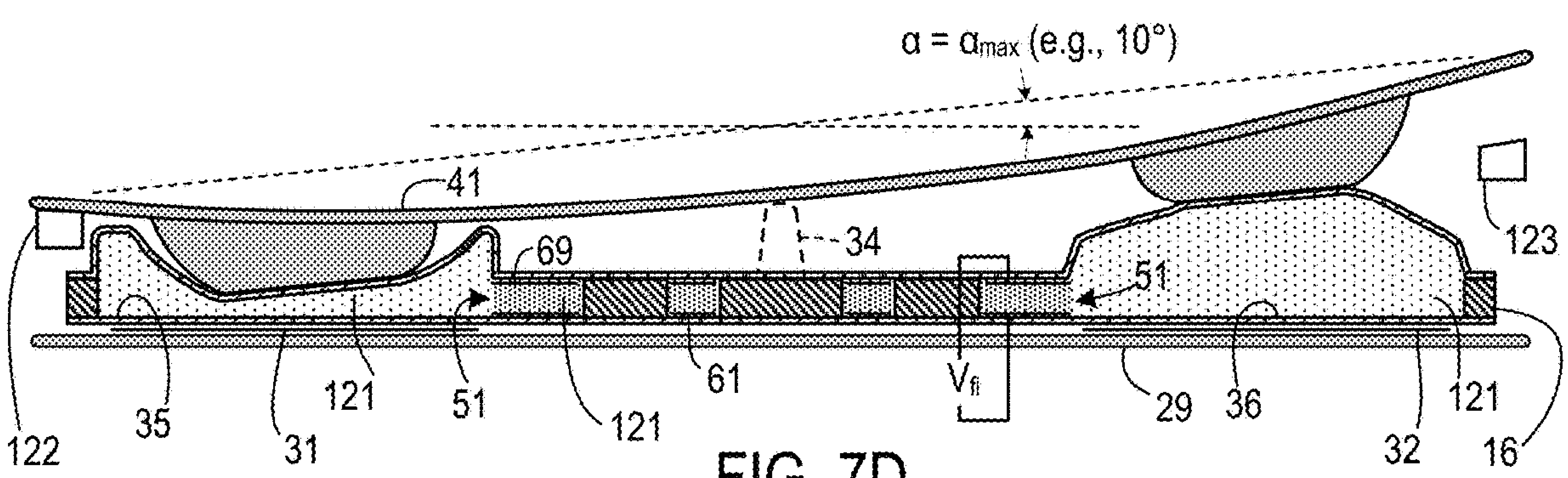


FIG. 7D

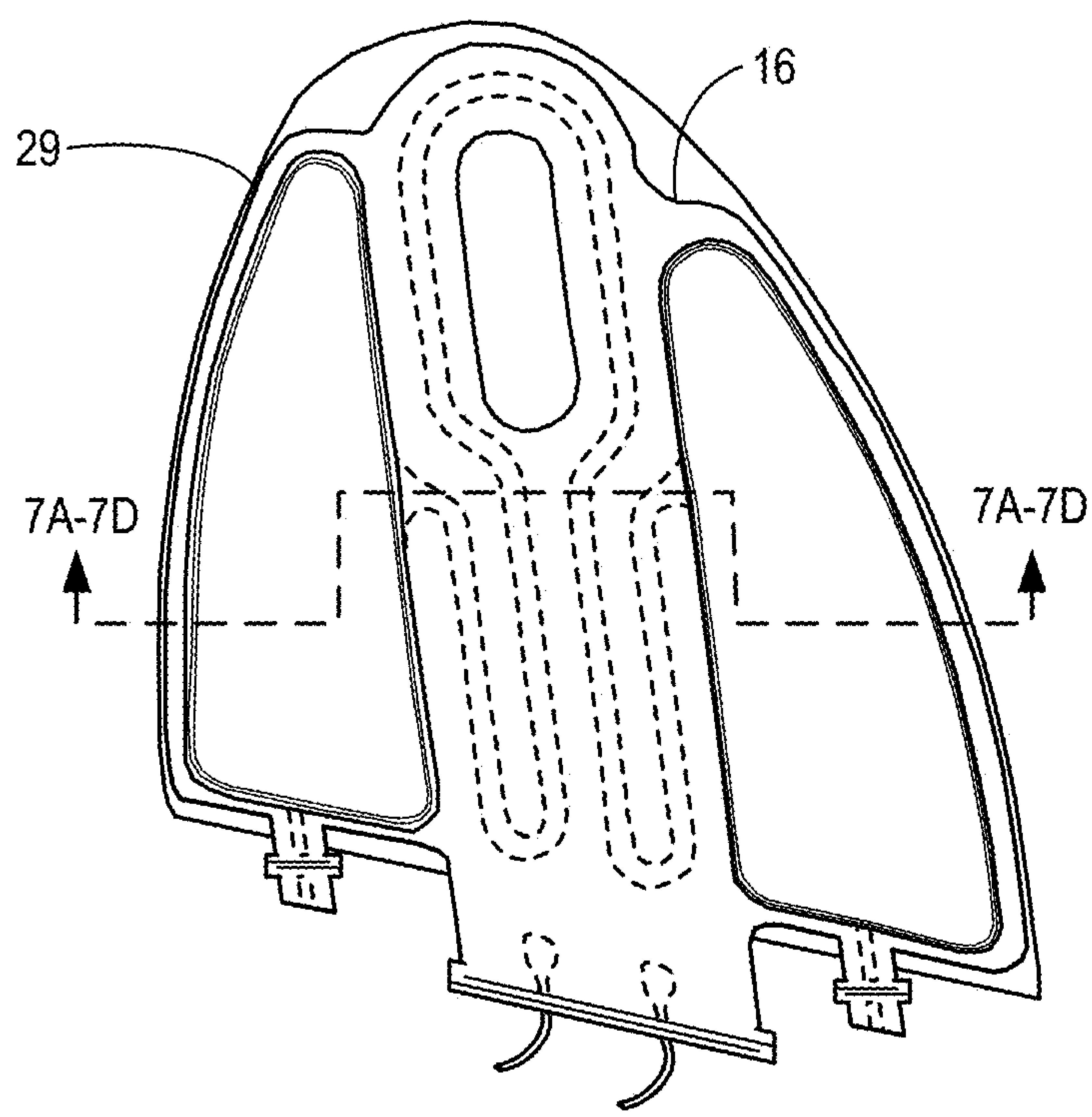


FIG. 7E

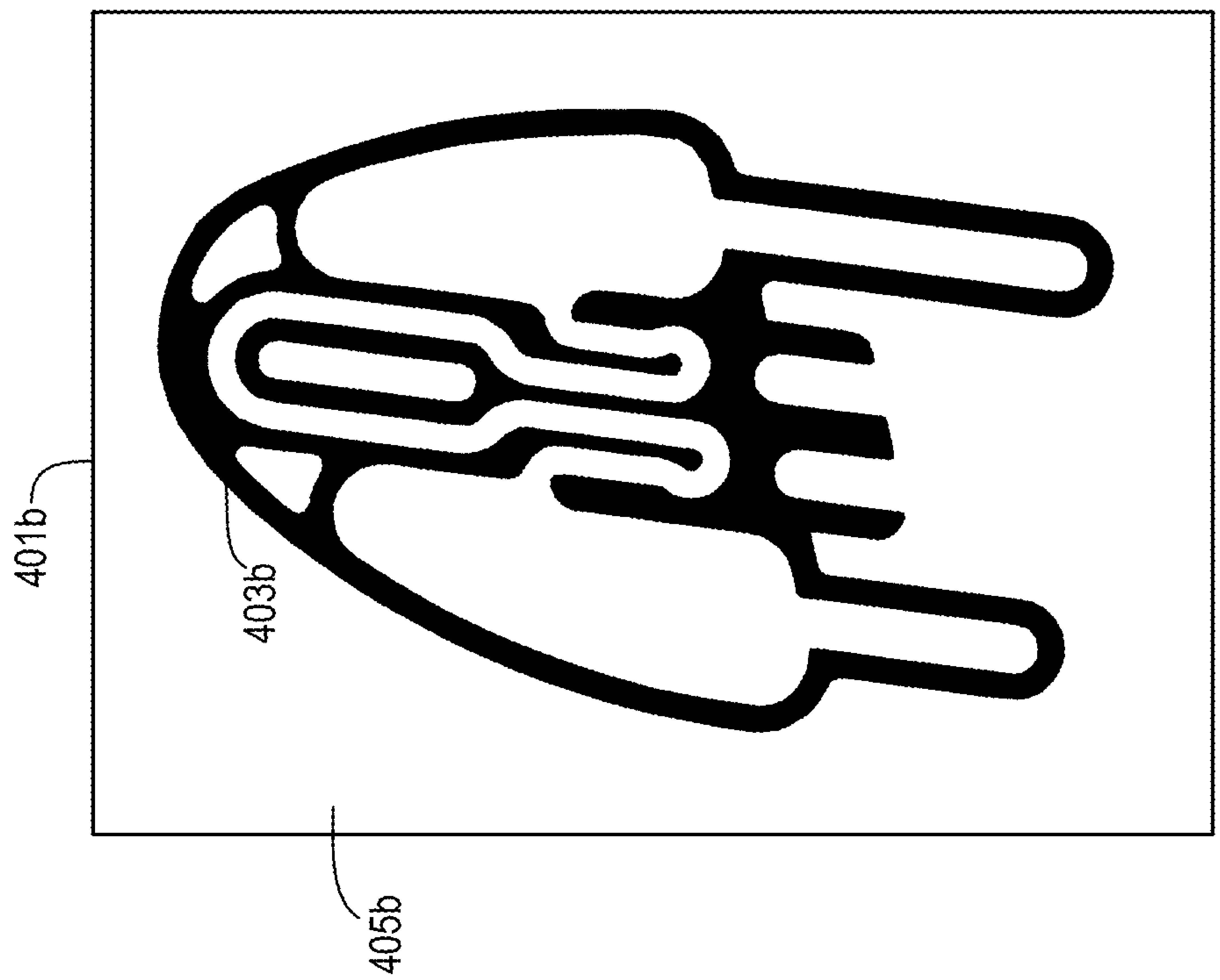


FIG. 8B

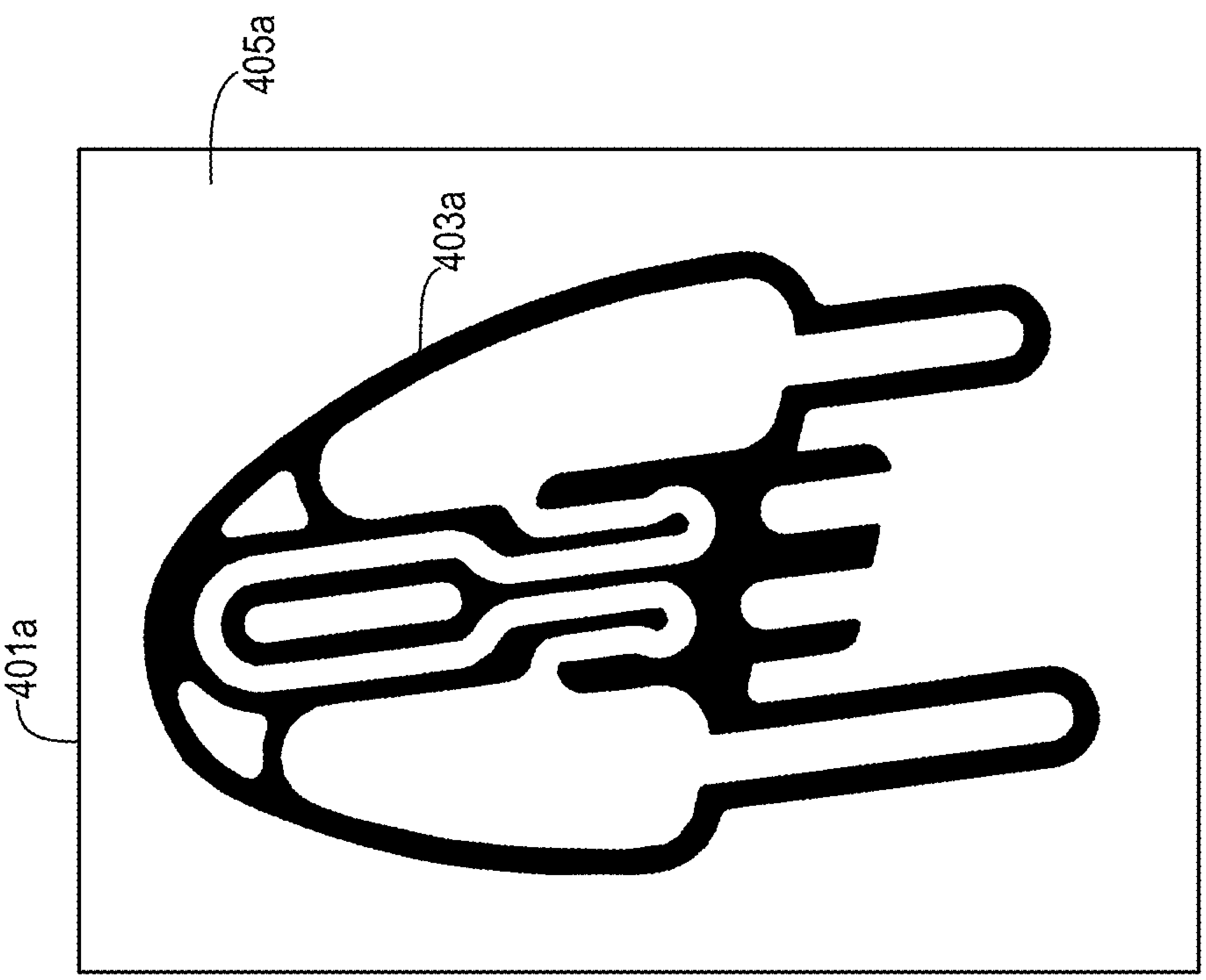


FIG. 8A

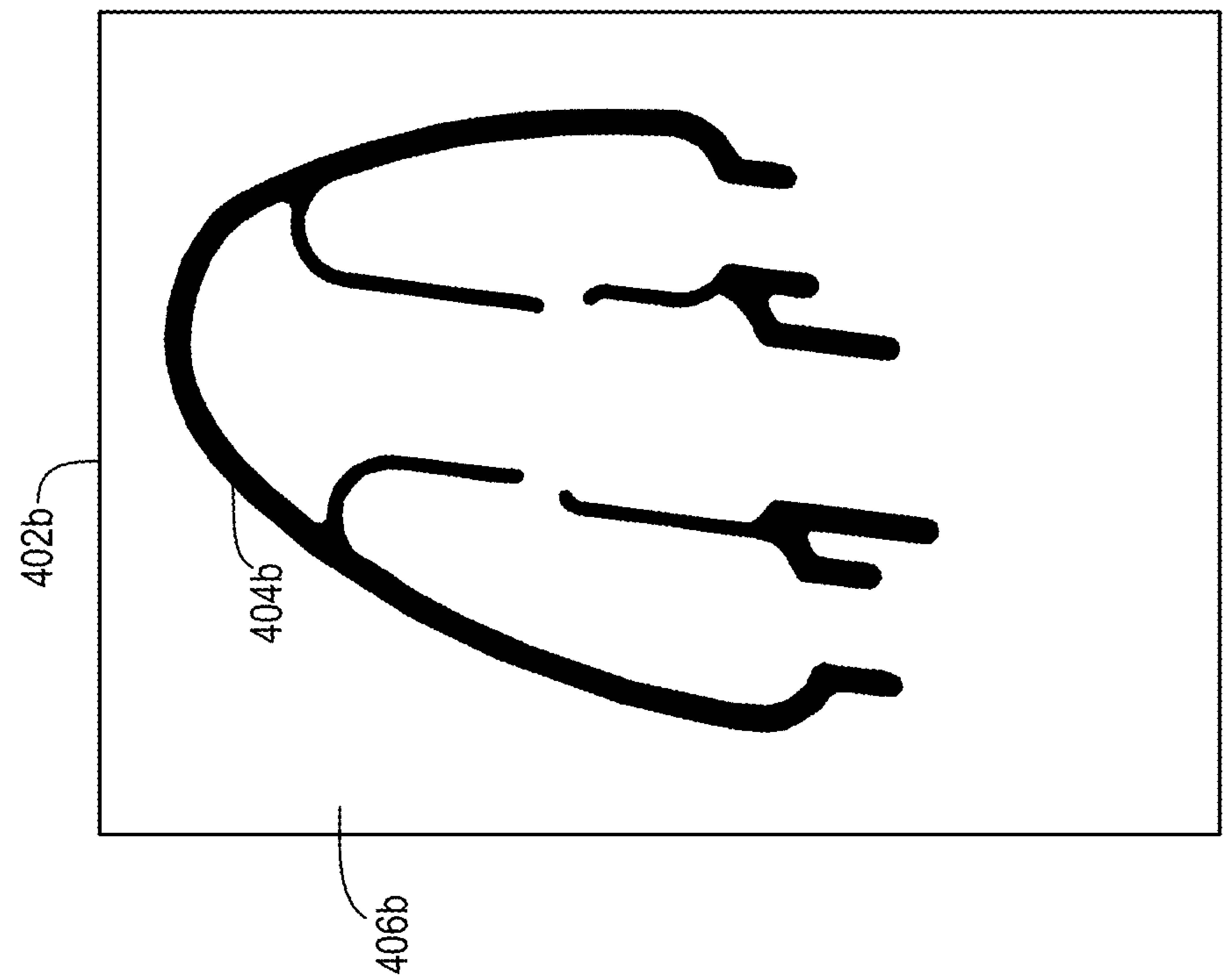


FIG. 8D

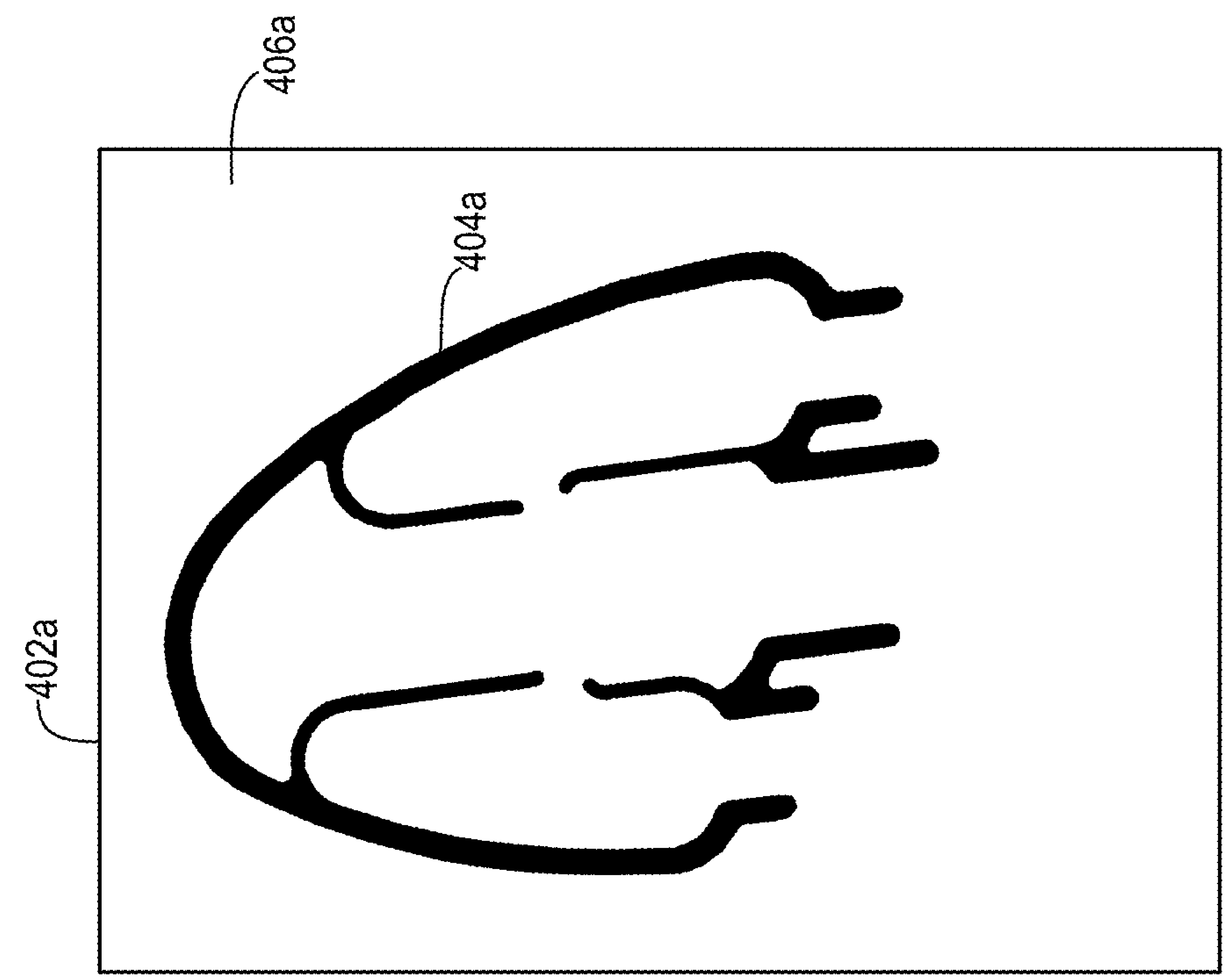


FIG. 8C

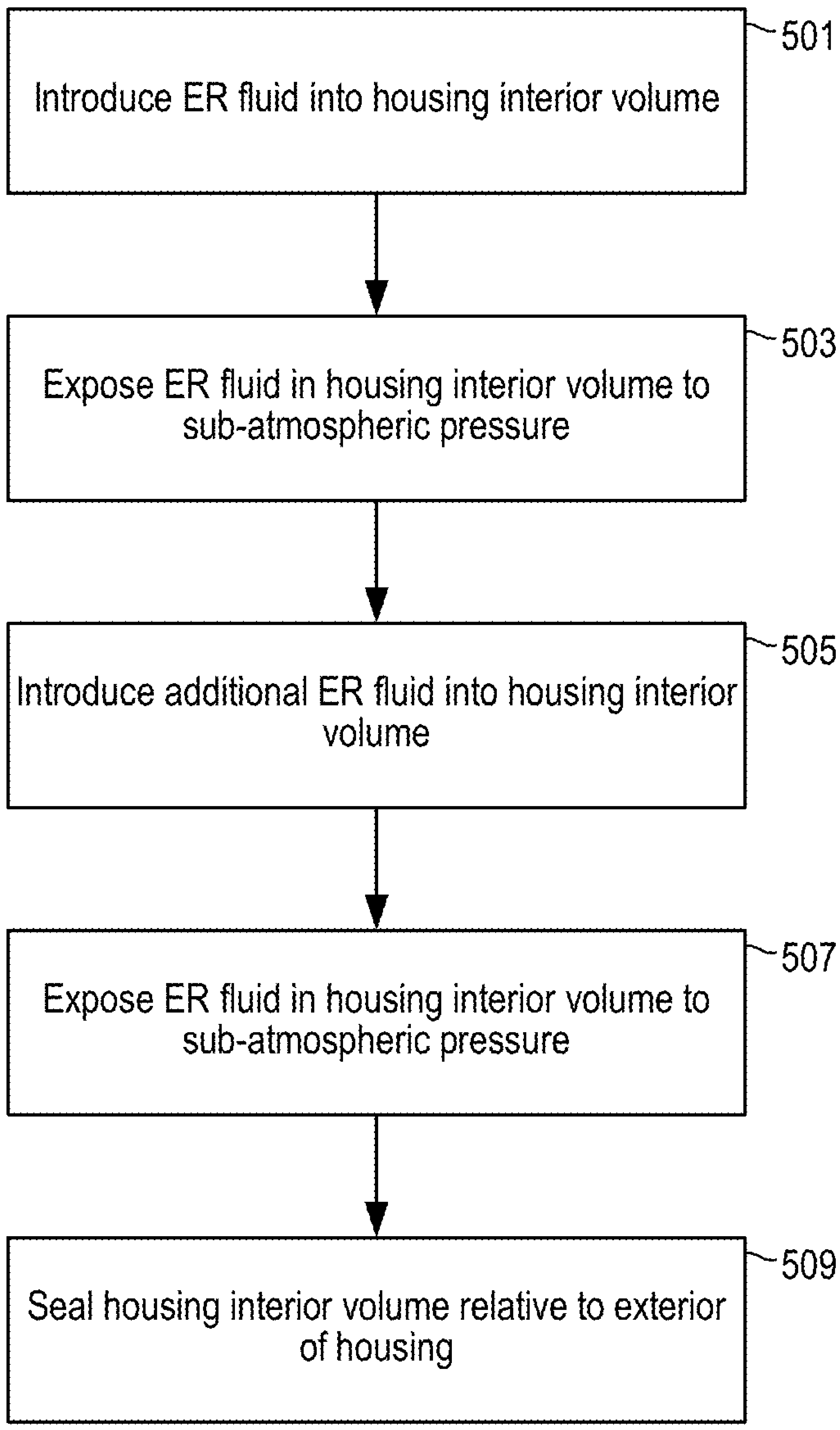

501
Introduce ER fluid into housing interior volume
503
Expose ER fluid in housing interior volume to sub-atmospheric pressure
505
Introduce additional ER fluid into housing interior volume
507
Expose ER fluid in housing interior volume to sub-atmospheric pressure
509
Seal housing interior volume relative to exterior of housing

FIG. 9

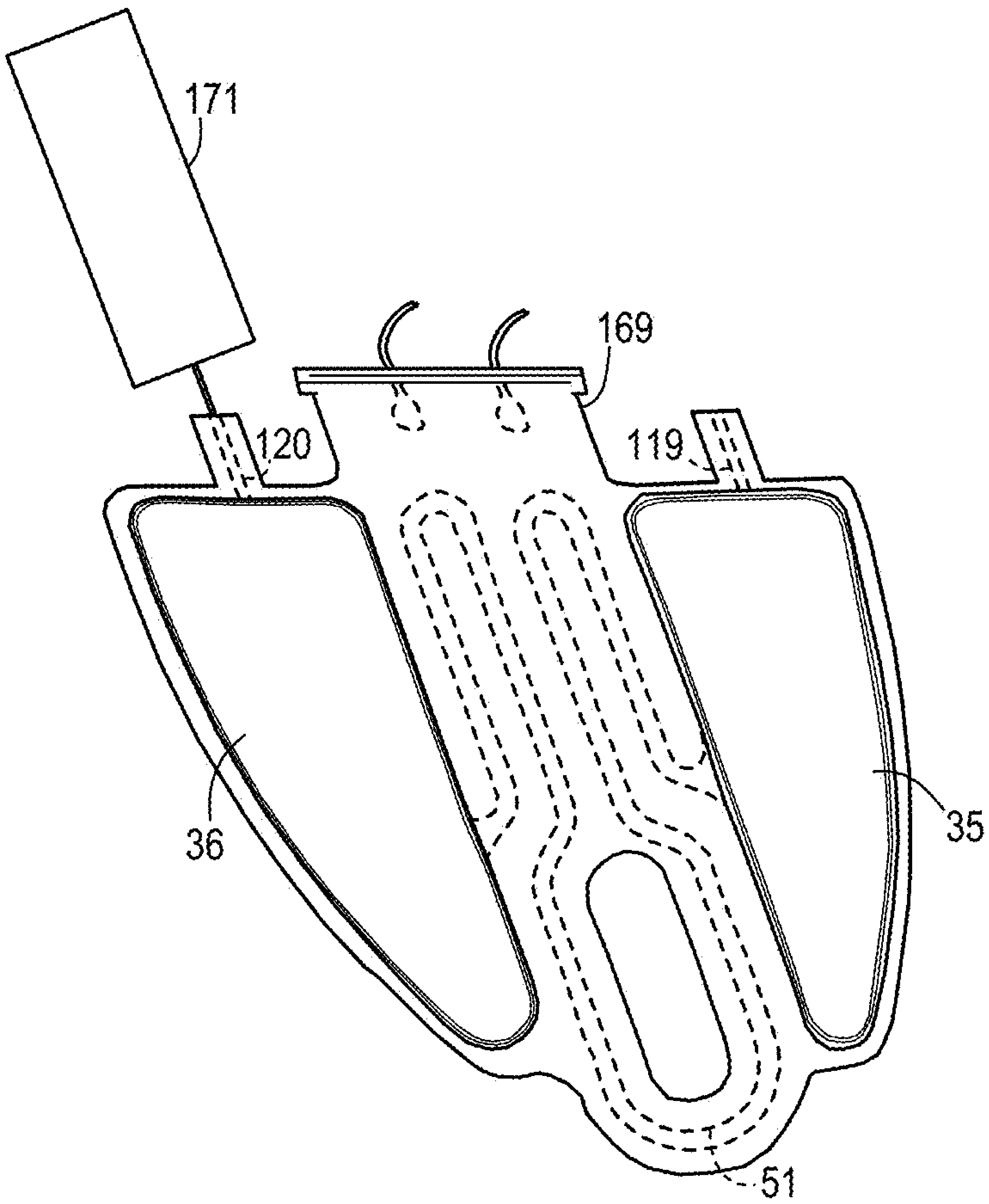


FIG. 10A

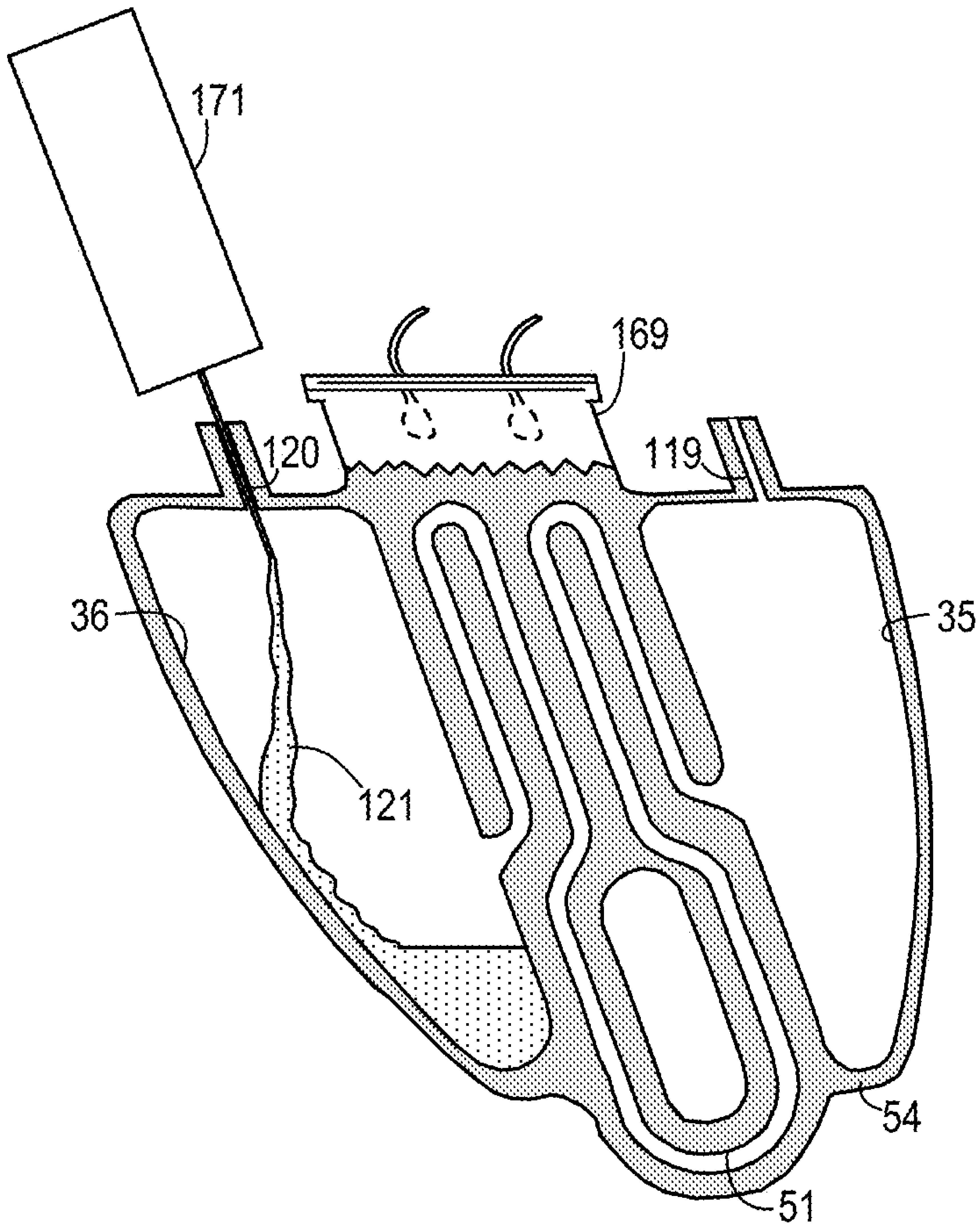


FIG. 10B

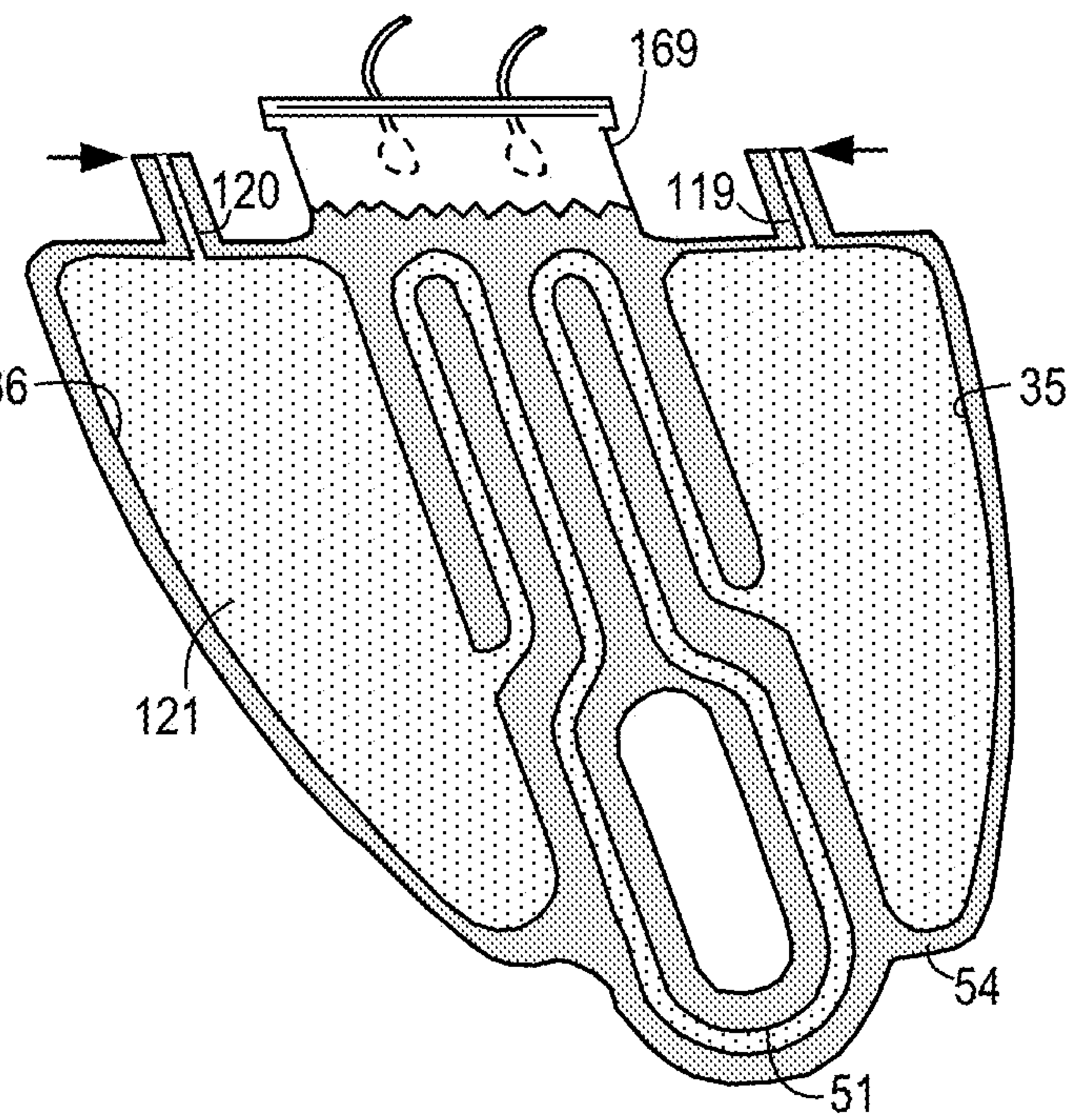


FIG. 10C

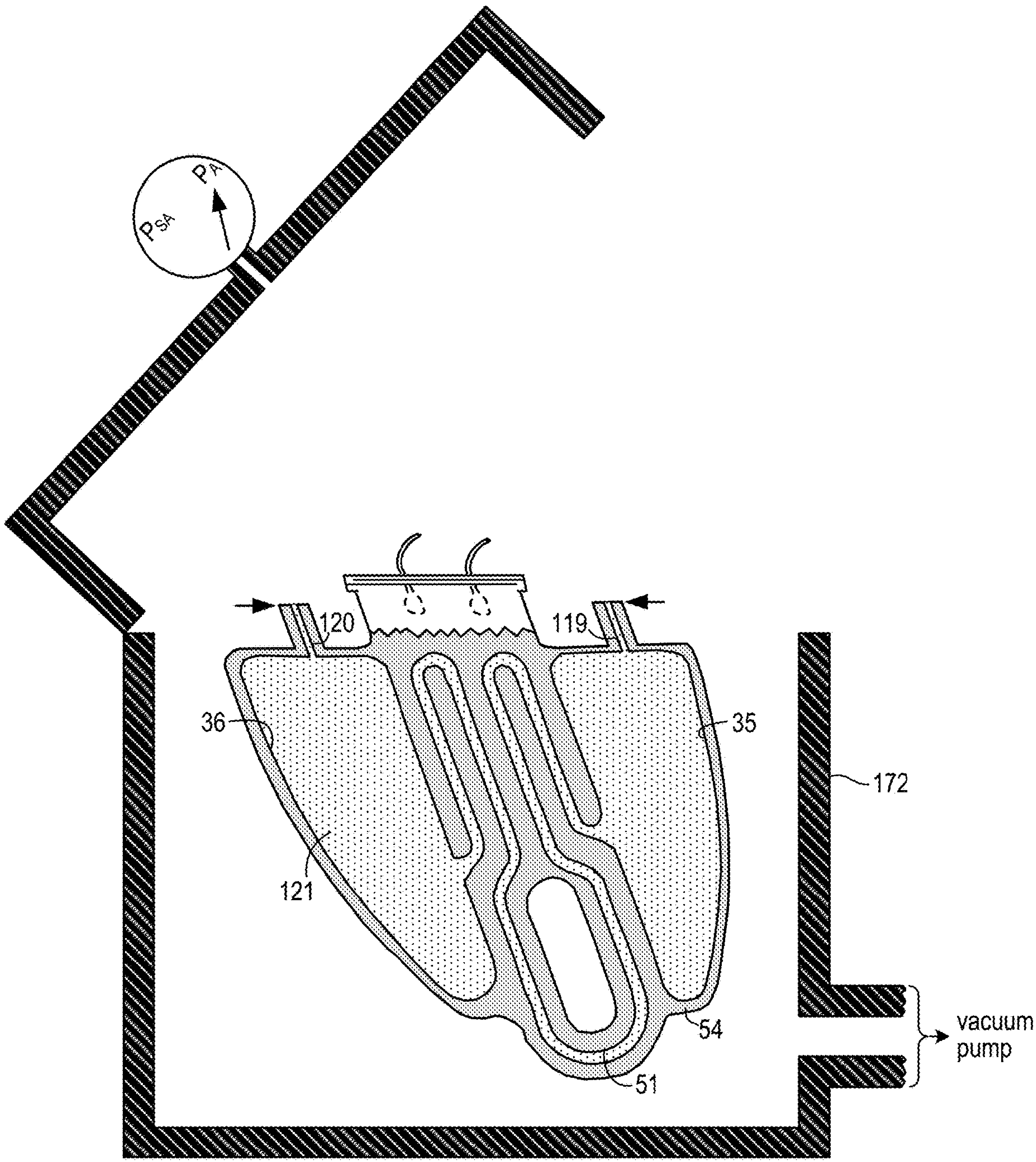


FIG. 10D

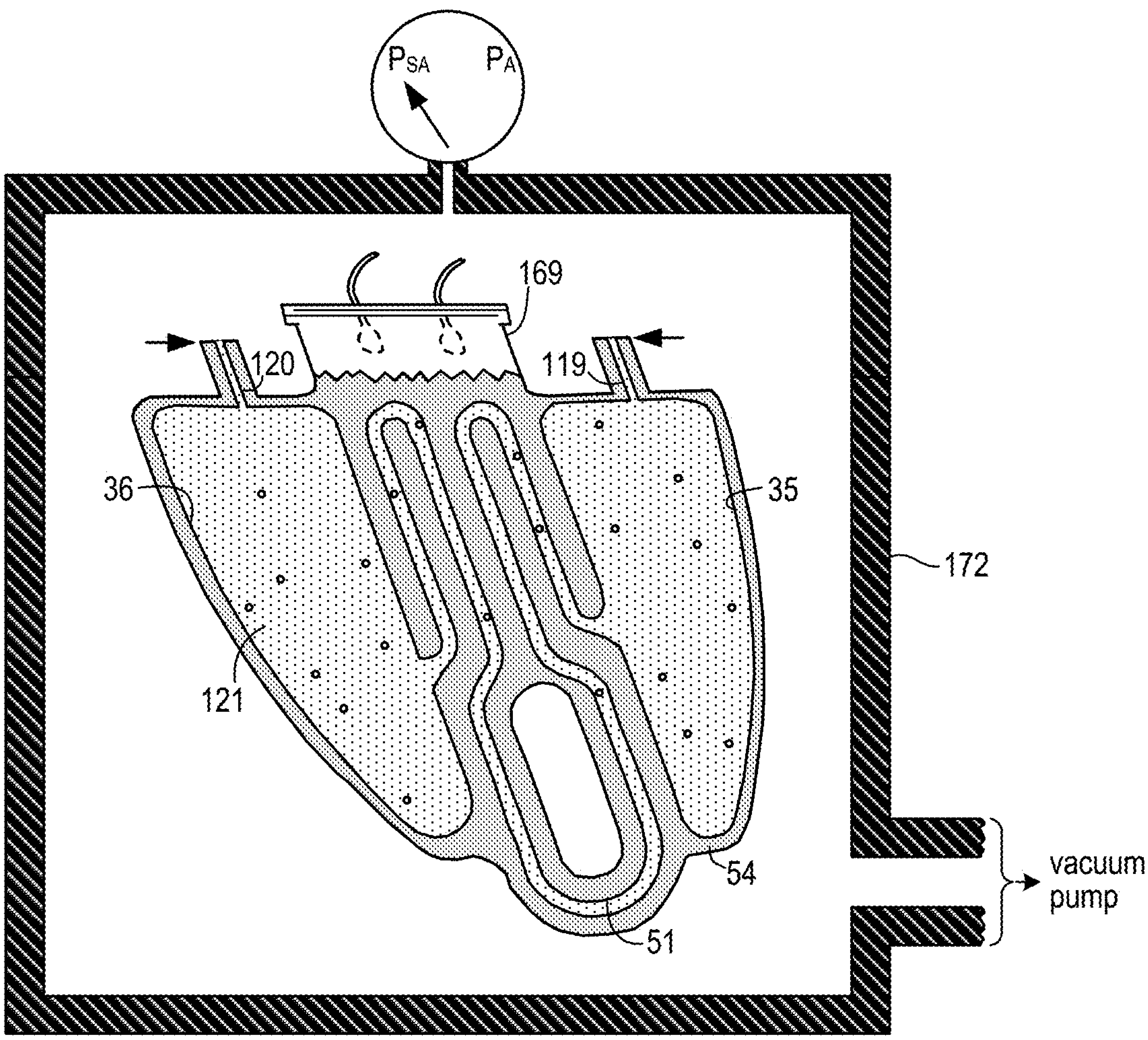


FIG. 10E

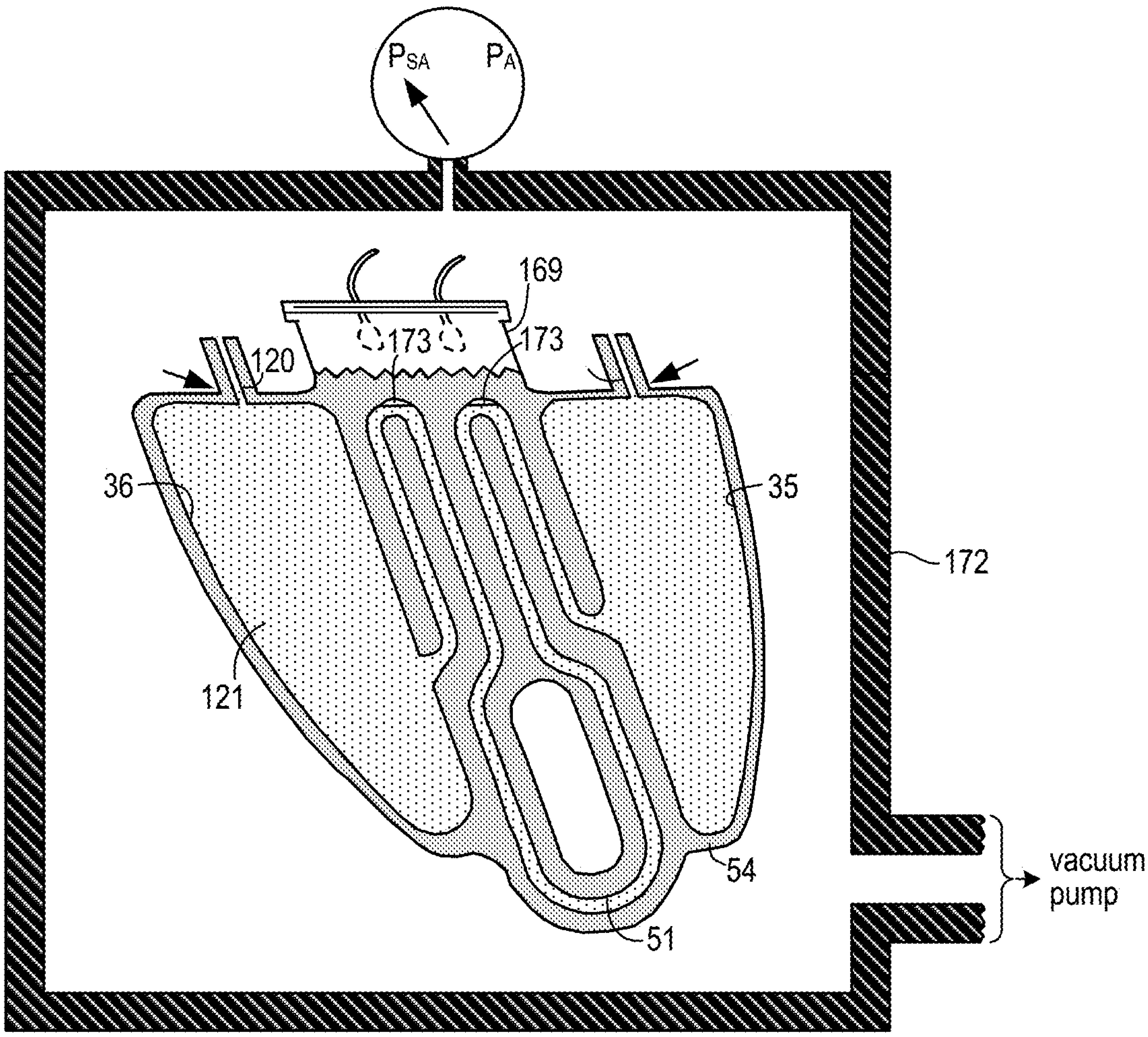


FIG. 10F

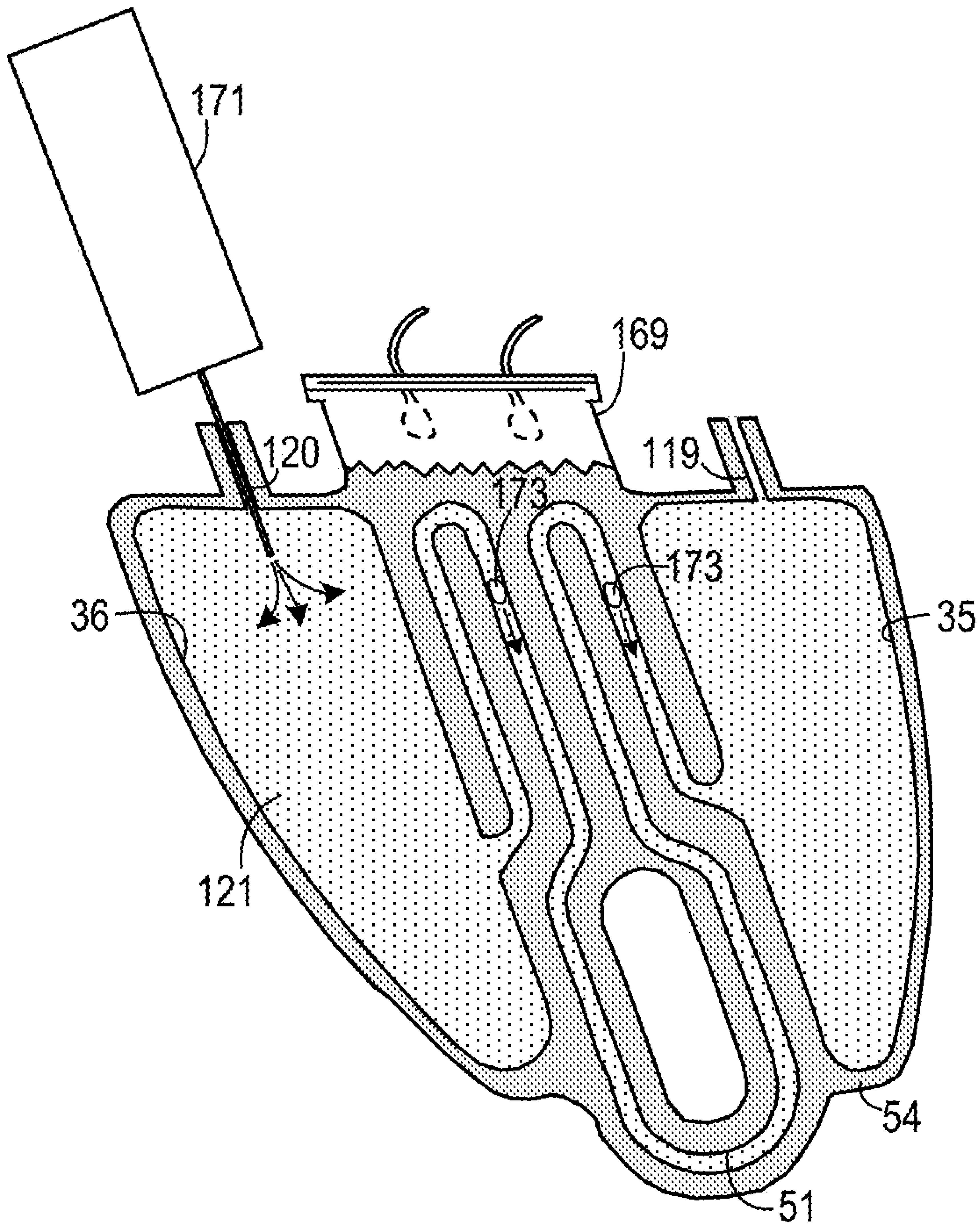


FIG. 10G

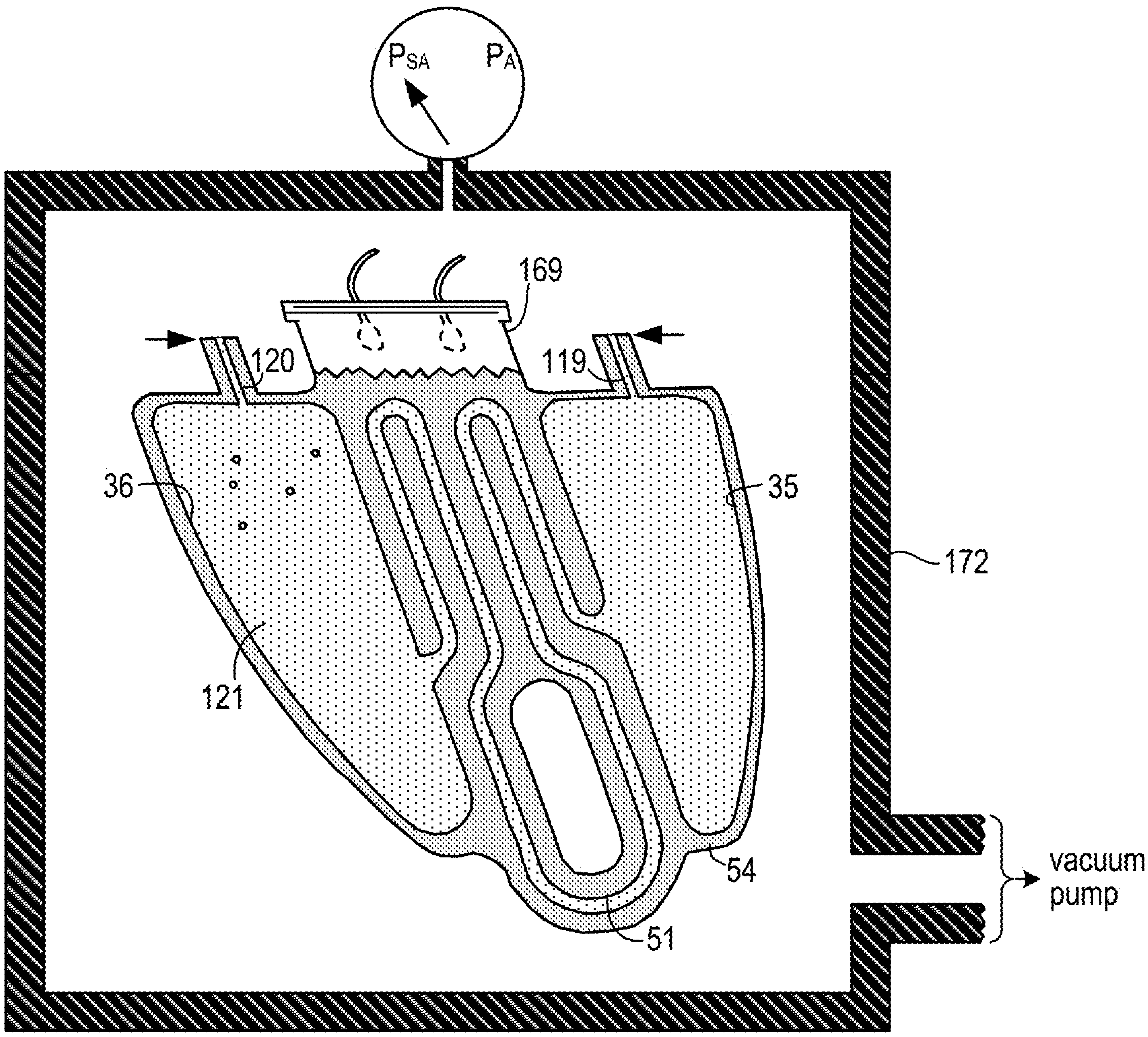


FIG. 10H

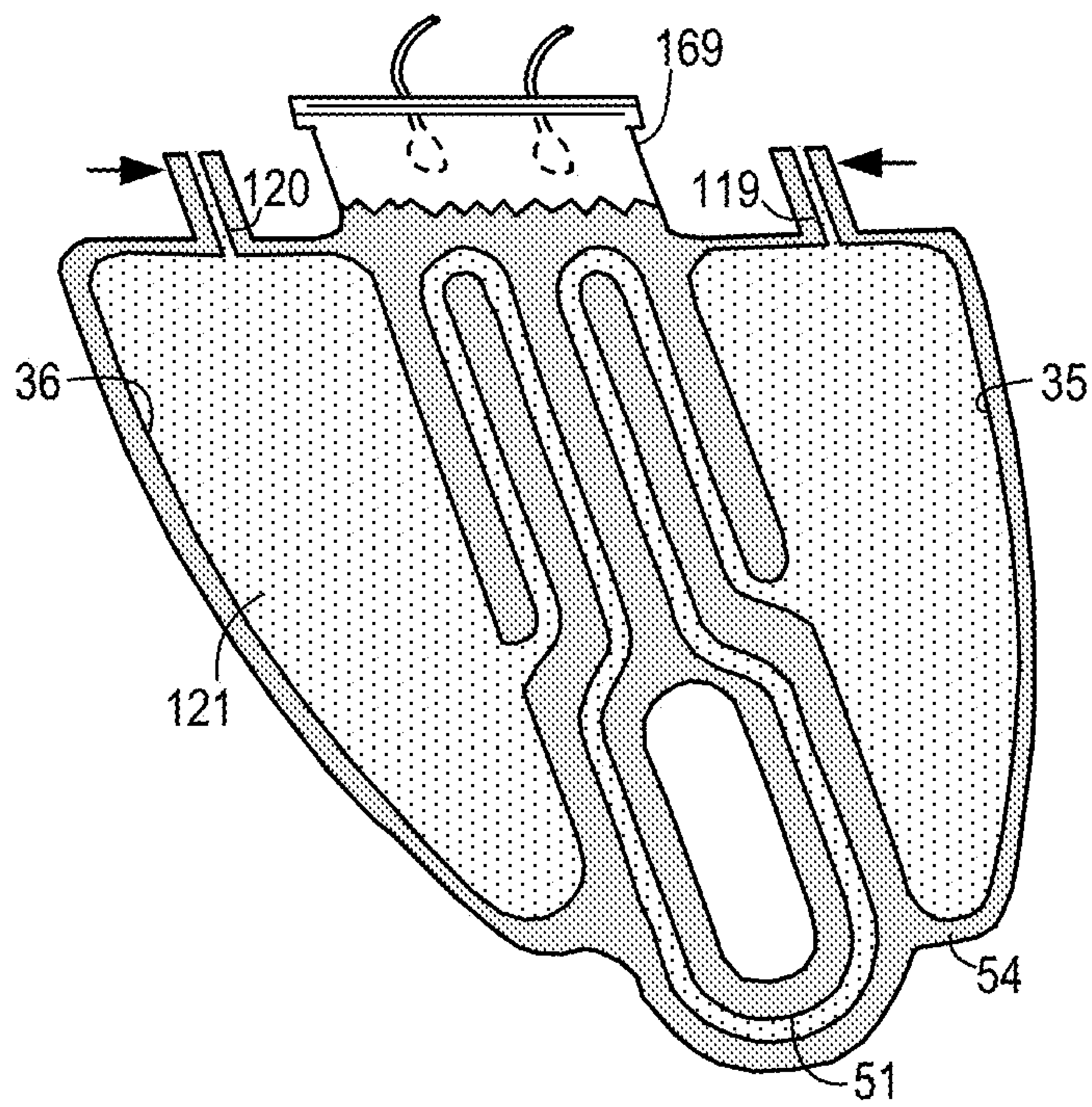


FIG. 10I

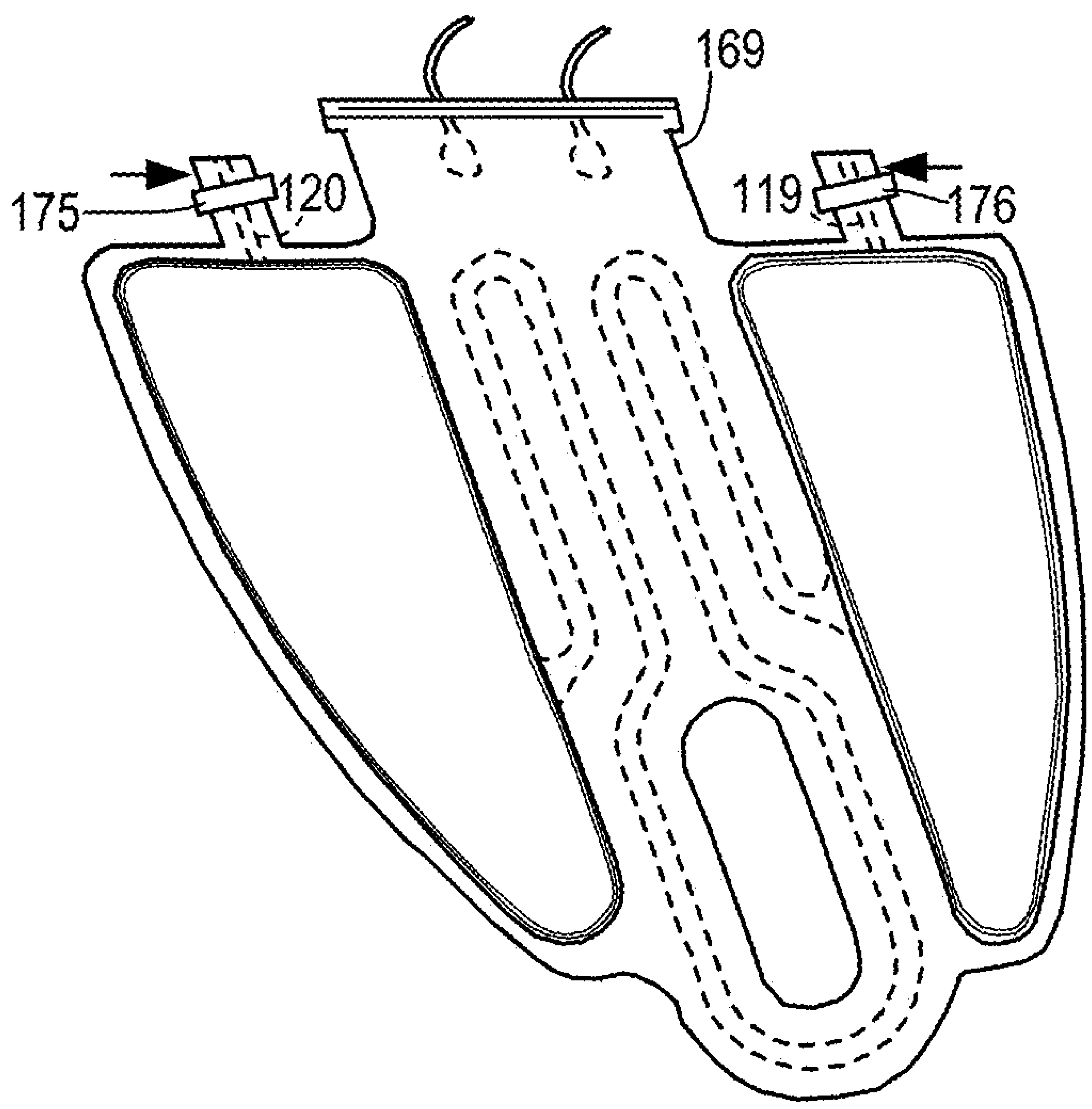


FIG. 10J

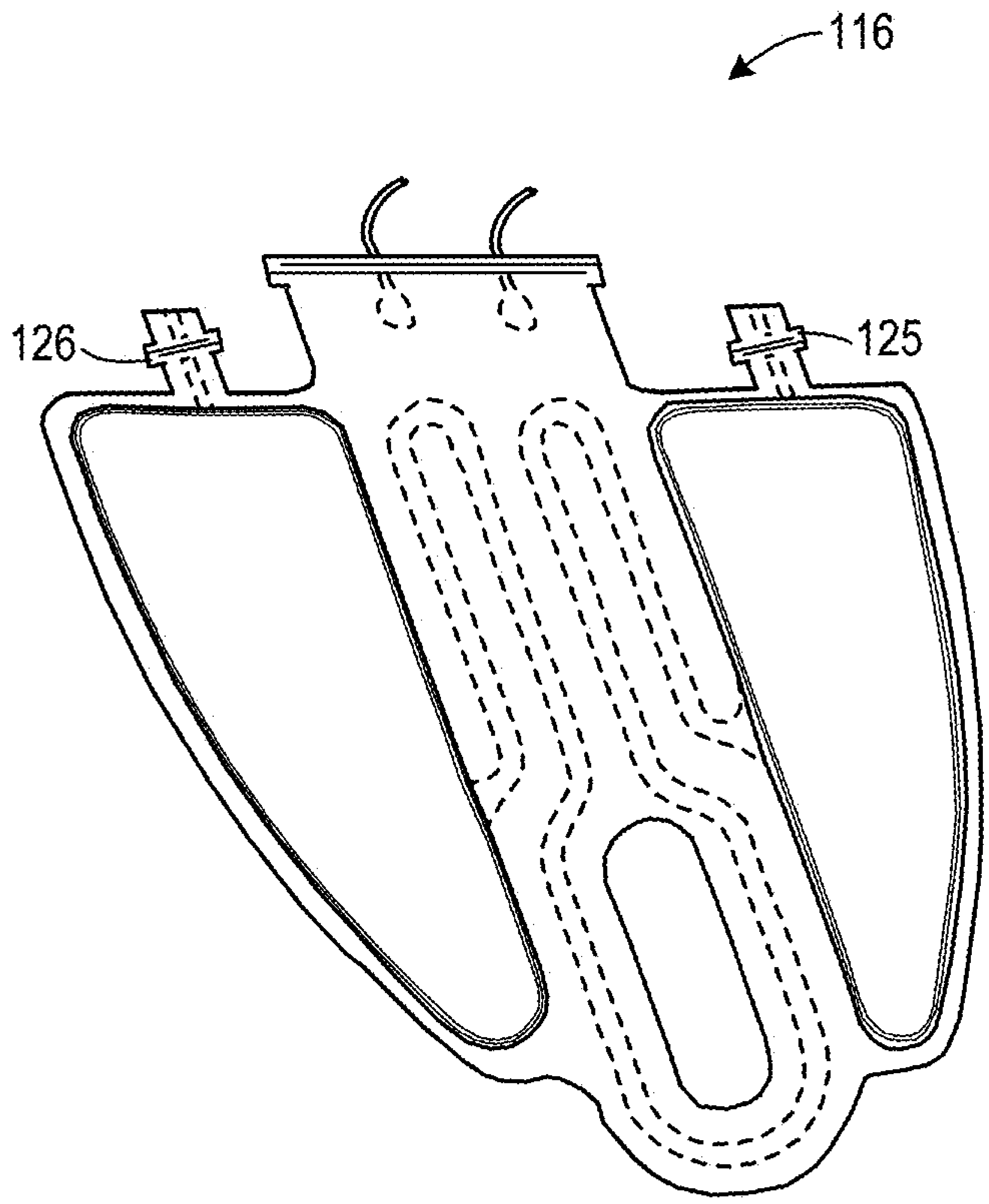


FIG. 10K

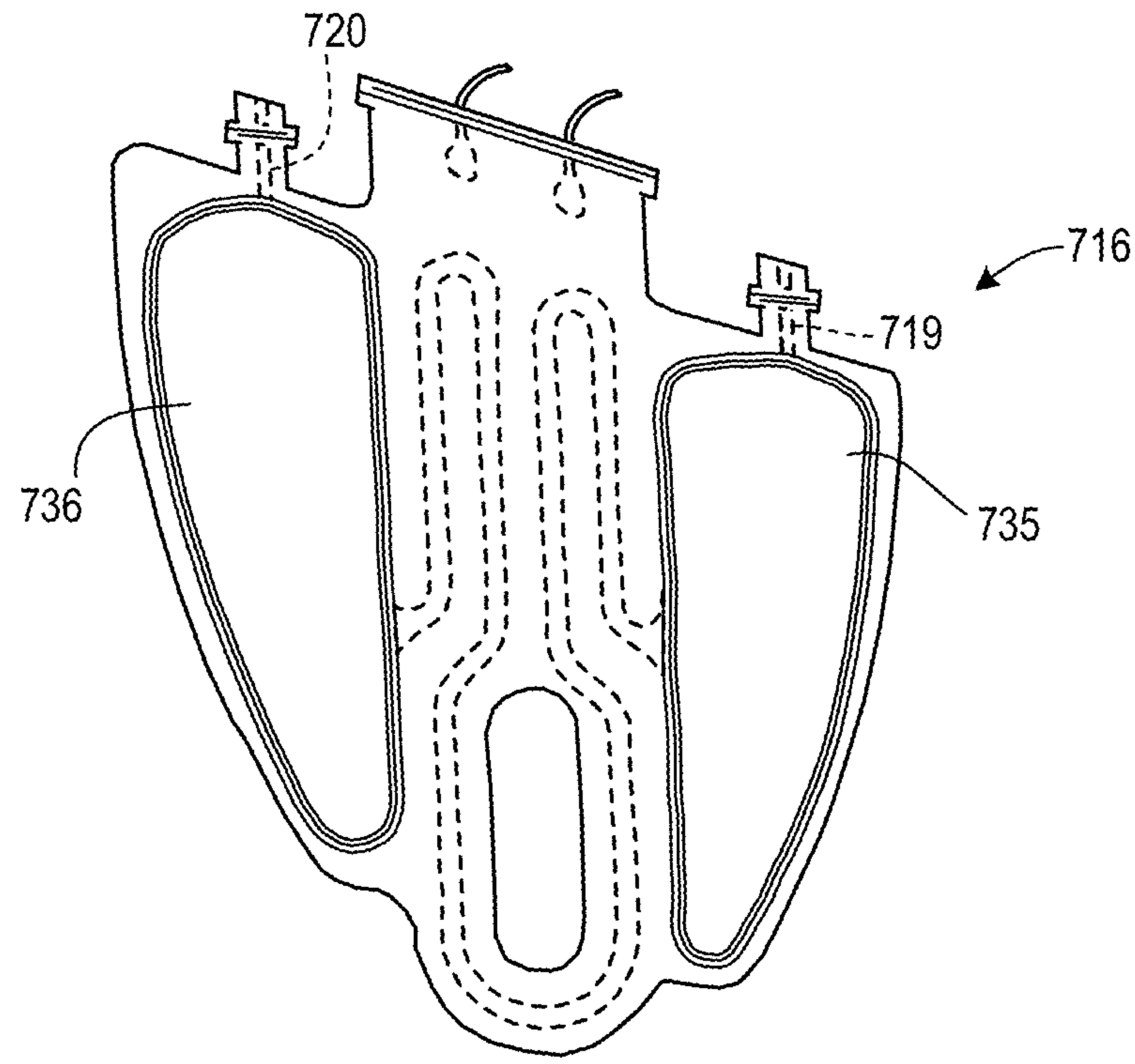


FIG. 11A

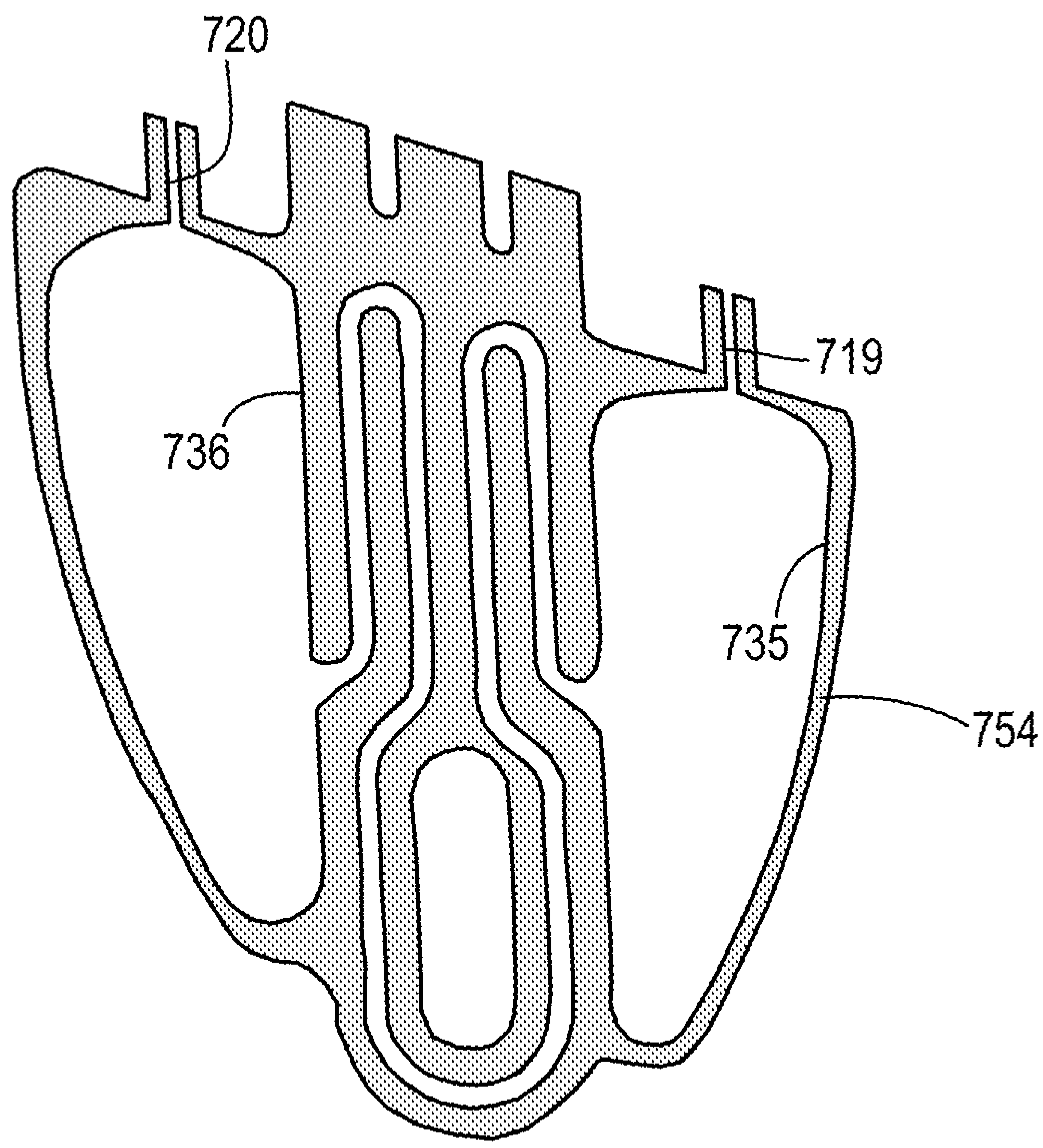


FIG. 11B

METHOD OF FILLING ELECTRORHEOLOGICAL FLUID STRUCTURE

CROSS REFERENCE TO RELATED APPLICATION

This application claims priority to U.S. provisional patent application No. 62/260,897, titled "METHOD OF FILLING ELECTRORHEOLOGICAL FLUID STRUCTURE" and filed Nov. 30, 2015. Application No. 62/260,897, in its entirety, is incorporated by reference herein.

BACKGROUND

Conventional articles of footwear generally include an upper and a sole structure. The upper provides a covering for the foot and securely positions the foot relative to the sole structure. The sole structure is secured to a lower portion of the upper and is configured so as to be positioned between the foot and the ground when a wearer is standing, walking, or running.

Conventional footwear is often designed with the goal of optimizing a shoe for a particular condition or set of conditions. For example, sports such as tennis and basketball require substantial side-to-side movements. Shoes designed for wear while playing such sports often include substantial reinforcement and/or support in regions that experience more force during sideways movements. As another example, running shoes are often designed for forward movement by a wearer in a straight line. Difficulties can arise when a shoe must be worn during changing conditions, or during multiple different types of movements.

SUMMARY

This Summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the invention.

In at least some embodiments, a method of filling an electrorheological fluid structure may include introducing electrorheological fluid into an interior volume of a housing. The electrorheological fluid within the housing may then be subjected to a sub-atmospheric pressure. Subsequently, the interior volume may be sealed relative to an exterior of the housing.

Additional embodiments are described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Some embodiments are illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings and in which like reference numerals refer to similar elements.

FIG. **1** is a medial side view of a shoe according to some embodiments.

FIG. **2**A is a bottom view of the sole structure of the shoe of FIG. **1**.

FIG. **2**B is a bottom view of the sole structure of the shoe of FIG. **1**, but with a forefoot outsole element and an incline adjuster removed.

FIG. **2**C is a bottom view of the forefoot outsole element of the sole structure of the shoe of FIG. **1**.

FIG. **3** is a partially exploded medial perspective view of the sole structure of the shoe of FIG. **1**.

FIG. **4**A is an enlarged top view of an incline adjuster of the shoe of FIG. **1**.

FIG. **4**B is a rear edge view of the incline adjuster of FIG. **4**A.

FIG. **5**A is a top view of a bottom layer of the incline adjuster of FIG. **4**A.

FIG. **5**B is a top view of a middle layer of the incline adjuster of FIG. **4**A.

FIG. **5C1** is a top view of a top layer of the incline adjuster of FIG. **4**A.

FIG. **5C2** is a bottom view of the top layer of the incline adjuster of FIG. **4**A.

FIG. **5C3** is a partial area cross-sectional view of the top layer of the incline adjuster of FIG. **4**A.

FIG. **5D1** shows a first assembly operation in the fabrication of an incline adjuster according to some embodiments.

FIG. **5D2** shows a second assembly operation in the fabrication of an incline adjuster according to some embodiments.

FIG. **5D3** is a top view of a partially completed incline adjuster after bonding of layers but prior to filling with electrorheological fluid.

FIG. **6** is a block diagram showing electrical system components in the shoe of FIG. **1**.

FIGS. **7**A through **7**D are partially schematic area cross-sectional diagrams showing operation of the incline adjuster of the shoe of FIG. **1** when going from a minimum incline condition to a maximum incline condition.

FIG. **7**E is a top view of the incline adjuster and a bottom plate of the shoe of FIG. **1**, and showing the approximate locations of sectioning lines corresponding to the views of FIGS. **7**A-**7**D.

FIGS. **8**A and **8**B are top views of two sides of a first RF welding tool according to some embodiments.

FIGS. **8**C and **8**D are top views of two sides of a second RF welding tool according to some embodiments.

FIG. **9** is a block diagram showing steps in a method according to some embodiments.

FIGS. **10**A through **10**K are partially schematic drawings showing various operations during a method according to FIG. **9**.

FIG. **11**A is a top view of an incline adjuster according to another embodiment.

FIG. **11**B is a top view of a middle layer of the incline adjuster of FIG. **11**A.

DETAILED DESCRIPTION

In various types of activities, it may be advantageous to change the shape of a shoe or shoe portion while a wearer of that shoe is running or otherwise participating in the activity. In many running competitions, for example, athletes race around a track having curved portions, also known as "bends." In some cases, particularly shorter events such as 200 meter or 400 meter races, athletes may be running at sprint paces on a track bend. Running on a flat curve at a fast pace is biomechanically inefficient, however, and may require awkward body movements. To counteract such effects, bends of some running tracks are banked. This banking allows more efficient body movement and typically results in faster running times. Tests have shown that similar advantages can be achieved by altering the shape of a shoe. In particular, running on a flat track bend in a shoe having a footbed that is inclined relative to the ground can mimic the benefits of running on a banked bend in a shoe having a non-inclined footbed. However, an inclined footbed is a disadvantage on straight portions of a running track. Footwear that can provide an inclined footbed when running on a bend and reduce or eliminate the incline when running on a straight track section would offer a significant advantage.

In footwear according to some embodiments, electrorheological (ER) fluid is used to change the shape of one or more shoe portions. ER fluids typically comprise a non-conducting oil or other fluid in which very small particles are suspended. In some types of ER fluid, the particles may be have diameters of 5 microns or less and may be formed from polystyrene or another polymer having a dipolar molecule. When an electric field is imposed across the ER fluid, the viscosity of the fluid increases as the strength of that field increases. As described in more detail below, this effect can be used to control transfer of fluid and modify the shape of a footwear component. Although track shoe embodiments are initially described, other embodiments include footwear intended for other sports or activities.

To assist and clarify subsequent description of various embodiments, various terms are defined herein. Unless context indicates otherwise, the following definitions apply throughout this specification (including the claims). "Shoe" and "article of footwear" are used interchangeably to refer to an article intended for wear on a human foot. A shoe may or may not enclose the entire foot of a wearer. For example, a shoe could include a sandal-like upper that exposes large portions of a wearing foot. The "interior" of a shoe refers to space that is occupied by a wearer's foot when the shoe is worn. An interior side, surface, face, or other aspect of a shoe component refers to a side, surface, face or other aspect of that component that is (or will be) oriented toward the shoe interior in a completed shoe. An exterior side, surface, face or other aspect of a component refers to a side, surface, face or other aspect of that component that is (or will be) oriented away from the shoe interior in the completed shoe. In some cases, the interior side, surface, face or other aspect of a component may have other elements between that interior side, surface, face or other aspect and the interior in the completed shoe. Similarly, an exterior side, surface, face or other aspect of a component may have other elements between that exterior side, surface, face or other aspect and the space external to the completed shoe.

Shoe elements can be described based on regions and/or anatomical structures of a human foot wearing that shoe, and by assuming that the interior of the shoe generally conforms to and is otherwise properly sized for the wearing foot. A forefoot region of a foot includes the heads and bodies of the metatarsals, as well as the phalanges. A forefoot element of a shoe is an element having one or more portions located under, over, to the lateral and/or medial side of, and/or in front of a wearer's forefoot (or portion thereof) when the shoe is worn. A midfoot region of a foot includes the cuboid, navicular, and cuneiforms, as well as the bases of the metatarsals. A midfoot element of a shoe is an element having one or more portions located under, over, and/or to the lateral and/or medial side of a wearer's midfoot (or portion thereof) when the shoe is worn. A heel region of a foot includes the talus and the calcaneus. A heel element of a shoe is an element having one or more portions located under, to the lateral and/or medial side of, and/or behind a wearer's heel (or portion thereof) when the shoe is worn. The forefoot region may overlap with the midfoot region, as may the midfoot and heel regions.

Unless indicated otherwise, a longitudinal axis refers to a horizontal heel-toe axis along the center of the foot that is roughly parallel to a line along the second metatarsal and second phalanges. A transverse axis refers to a horizontal axis across the foot that is generally perpendicular to a longitudinal axis. A longitudinal direction is generally parallel to a longitudinal axis. A transverse direction is generally parallel to a transverse axis.

FIG. **1** is a medial side view of a track shoe **10** according to some embodiments. The lateral side of shoe **10** has a similar configuration and appearance, but is configured to correspond to a lateral side of a wearer foot. Shoe **10** is configured for wear on a right foot and is part of a pair that includes a shoe (not shown) that is a mirror image of shoe **10** and is configured for wear on a left foot.

Shoe **10** includes an upper **11** attached to a sole structure **12**. Upper **11** may be formed from any of various types or materials and have any of a variety of different constructions. In some embodiments, for example, upper **11** may be knitted as a single unit and may not include a bootie of other type of liner. In some embodiments, upper **11** may be slip lasted by stitching bottom edges of upper **11** to enclose a foot-receiving interior space. In other embodiments, upper **11** may be lasted with a strobel or in some other manner. A battery assembly **13** is located in a rear heel region of upper **11** and includes a battery that provides electrical power to a controller. The controller is not visible in in FIG. **1**, but is described below in connection with other drawing figures.

Sole structure **12** includes a footbed **14**, an outsole **15**, and an incline adjuster **16**. Incline adjuster **16** is situated between outsole **15** and footbed **14** in a forefoot region. As explained in more detail below, incline adjuster **16** includes a medial side fluid chamber that supports a medial forefoot portion of footbed **14**, as well as a lateral side fluid chamber that supports a lateral forefoot portion of footbed **14**. ER fluid may be transferred between those chambers through a connecting transfer channel that is in fluid communication with the interiors of both chambers. That fluid transfer may raise the height of one chamber relative to the other chamber, resulting in an incline in a portion of footbed **14** located over the chambers. When further flow of ER fluid through the channel is interrupted, the incline is maintained until ER fluid flow is allowed to resume.

Outsole **15** forms the ground-contacting portion of sole structure **12**. In the embodiment of shoe **10**, outsole **15** includes a forward outsole section **17** and a rear outsole section **18**. The relationship of forward outsole section **17** and rear outsole section **18** can be seen by comparing FIG. **2**A, a bottom view of sole structure **12**, and FIG. **2**B, a bottom view of sole structure **12** with forefoot outsole section **17** and incline adjuster **16** removed. FIG. **2**C is a bottom view of forefoot outsole section **17** removed from sole structure **12**. As seen in FIG. **2**A, forward outsole section **17** extends through forefoot and central midfoot regions of sole structure **12** and tapers to a narrowed end **19**. End **19** is attached to rear outsole section **18** at a joint **20** located in the heel region. Rear outsole section **18** extends over side midfoot regions and over the heel region and is attached to footbed **14**. Forward outsole section **17** is also coupled to footbed **14** by a fulcrum element and by the above-mentioned fluid chambers of incline adjuster **16**. Forefoot outsole section **17** pivots about a longitudinal axis L**1** passing through joint **20** and through the forefoot fulcrum element. In particular, and as explained below, forefoot outsole section **17** rotates about axis L**1** as a forefoot portion of footbed **14** inclines relative to forefoot outsole section **17**.

Outsole **15** may be formed of a polymer or polymer composite and may include rubber and/or other abrasion-resistant material on ground-contacting surfaces. Traction elements **21** may be molded into or otherwise formed in the bottom of outsole **15**. Forefoot outsole section **17** may also include receptacles to hold one or more removable spike elements **22**. In other embodiments, outsole **15** may have a different configuration.

Footbed **14** includes a midsole **25**. In the embodiment of shoe **10**, midsole **25** has a size and a shape approximately corresponding to a human foot outline, is a single piece that extends the full length and width of footbed **14**, and includes a contoured top surface **26** (shown in FIG. **3**). The contour of top surface **26** is configured to generally correspond to the shape of the plantar region of a human foot and to provide arch support. Midsole **25** may be formed from ethylene vinyl acetate (EVA) and/or one or more other closed cell polymer foam materials. Midsole **25** may also have pockets **27** and **28** formed therein to house a controller and other electronic components, as described below. Upwardly extending medial and lateral sides of rear outsole section **18** may also provide additional medial and lateral side support to a wearer foot. In other embodiments, a footbed may have a different configuration, e.g., a midsole may cover less than all of a footbed or may be entirely absent, and/or a footbed may include other components.

FIG. **3** is a partially exploded medial perspective view of sole structure **12**. Bottom support plate **29** is located in a plantar region of shoe **10**. In the embodiment of shoe **10**, bottom support plate **29** is attached to a top surface **30** of forward outsole section **17**. Bottom support plate **29**, which may be formed from a relatively stiff polymer or polymer composite, helps to stiffen the forefoot region of forward outsole section **17** and provide a stable base for incline adjuster **16**. A medial force-sensing resistor (FSR) **31** and a lateral FSR **32** are attached to a top surface **33** of bottom support plate **29**. As explained below, FSRs **31** and **32** provide outputs that help determine pressures within chambers of incline adjuster **16**.

Fulcrum element **34** is attached to top surface **33** of lower support plate **29**. Fulcrum element **34** is positioned between FSRs **31** and **32** in a front portion of bottom support plate **29**. Fulcrum element **34** may be formed from polyurethane, silicon rubber, EVA, or from one or more other materials that are generally incompressible under loads that result when a wearer of shoe **10** runs. Fulcrum element **34** provides resistance to transverse and longitudinal forces applied to the incline adjuster **16**.

Incline adjuster **16** is attached to top surface **33** of lower support plate **29**. A medial fluid chamber **35** of incline adjuster **16** is positioned over medial FSR **31**. A lateral fluid chamber **36** of incline adjuster **16** is positioned over lateral FSR **32**. Incline adjuster **16** includes an aperture **37** through which fulcrum element **34** extends. At least a portion of fulcrum element **34** is positioned between chambers **35** and **36**. Additional details of incline adjuster **16** are discussed in connection with subsequent drawing figures. A top support plate **41** is also located in a plantar region of shoe **10** and is positioned over incline adjuster **16**. In the embodiment of shoe **10**, top support plate **41** is generally aligned with bottom support plate **29**. Top support plate **41**, which may also be formed from a relatively stiff polymer or polymer composite, provides a stable and relatively non-deformable region against which incline adjuster **16** may push, and which supports the forefoot region of footbed **14**.

A forefoot region portion of the midsole **25** underside is attached to the top surface **42** of top support plate **41**. Portions of the midsole **25** underside in the heel and side midfoot regions are attached to a top surface **43** of rear outsole section **18**. End **19** of forward outsole section **17** is attached to rear outsole section **18** behind the rear-most location **44** of the front edge of section **18** so as to form joint **20**. In some embodiments, end **19** may be a tab that slides into a slot formed in section **18** at or near location **44**, and/or may be wedged between top surface **43** and the underside of midsole **25**.

Also shown in FIG. **3** are a DC-to-high-voltage-DC converter **45** and a printed circuit board (PCB) **46** of a controller **47**. Converter **45** converts a low voltage DC electrical signal into a high voltage (e.g., 5000V) DC signal that is applied to electrodes within incline adjuster **16**. PCB **46** includes one or more processors, memory and other components and is configured to control incline adjuster **16** through converter **45**. PCB **46** also receives inputs from FSRs **31** and **32** and receives electrical power from battery unit **13**. PCB **46** and converter **45** may be attached to the top surface of forward outsole section **17** in a midfoot region **48**, and may also rest within pockets **28** and **27**, respectively, in the underside midsole **25**. Wires **23*a*** and **24*a*** electrically connect converter **45** to incline adjuster **16**. A terminal **23*b*** on a first end of wire **23*a*** is inserted into a connection passage **39** on the rear edge of incline adjuster **16** and attached to a portion of a conductive trace projecting into an access passage **39**, as described in more detail below. A terminal **24*b*** on a first end of wire **24*a*** is inserted into an access passage **40** on the rear edge of incline adjuster **16** and attached to a portion of a separate conductive trace projecting into passage **40**, as described in more detail below. In some embodiments, terminals **23*b*** and **24*b*** may simply be portions of conductors of wires **23*a*** and **23*b*** that have been exposed by removing insulating jacket material. In other embodiments, separate terminal structures may be added. Second ends of wires **23*a*** and **24*a*** are connected to appropriate terminals of converter **45**. Additional sets of wires, not shown, connect converter **45** and PCB **46** and connect PCB **46** to battery assembly **13**.

FIG. **4**A is an enlarged top view of incline adjuster **16** and attached wires **23*a*** and **24*a***. FIG. **4**B is a rear edge view of incline adjuster **16** from the location indicated in FIG. **4**A. Medial fluid chamber **35** is in fluid communication with lateral fluid chamber **36** through a fluid transfer channel **51**. An ER fluid fills chambers **35** and **36** and transfer channel **51**. One example of an ER fluid that may be used in some embodiments is sold under the name "RheOil 4.0" by Fludicon GmbH, Landwehrstrasse 55, 64293 Darmstadt, Deutschland (Germany). In the present example, it is assumed that the top of incline adjuster **16** is formed by an opaque layer, and thus transfer channel **51** is indicated in FIG. **4**A with broken lines. In some embodiments, the top and/or other layers of an incline adjuster may be transparent or translucent.

Access passages **39** and **40** are similarly indicated in FIG. **4**A with broken lines. Terminals **23*b*** and **24*b*** have been inserted into passages **39** and **40** and welded in place, as described in more detail below. As a result of that welding, a rear portion of incline adjuster **16** around passages **39** and **40** has been flattened to form a crimp **151**. Within crimp **151**, layer **54** has melted and sealed around the outer surfaces of wires **23*a*** and **23*b***. In at least some embodiments, wires **23*a*** and **24*a*** are attached to incline adjuster **16** prior to filling with ER fluid.

Transfer channel **51** has a serpentine shape so as to provide increased surface area for electrodes within channel **51** to create an electrical field in fluid within channel **51**. For example, and as seen in FIG. **4**A, channel **51** includes three 180° curved sections joining other sections of channel **51** that cover the space between chambers **35** and **36**. In some embodiments, transfer channel **51** may have a maximum height h (FIG. **4**B) of 1 millimeter (mm), an average width (w) of 2 mm, and a minimum length along the flow direction of at least 257 mm.

In some embodiments, height of the transfer channel may practically be limited to a range of at least 0.250 mm to not more than 3.3 mm. An incline adjuster constructed of pliable material may be able to bend with the shoe during use. Bending across the transfer channel locally decreases the height at the point of bending. If sufficient allowance is not made, the corresponding increase in electric field strength may exceed the maximum dielectric strength of the ER fluid, causing the electric field to collapse. In the extreme, electrodes could become so close so as to actually touch, with the same resultant electric field collapse.

The viscosity of ER fluid increases with the applied electric field strength. The effect is non-linear and the optimum field strength is in the range of 3 to 6 kilovolts per millimeter (kV/mm). The high-voltage dc-dc converter used to boost the 3 to 5 V of the battery may be limited by physical size and safety considerations to less than 2 W or a maximum output voltage of less than or equal to 10 kV. To keep the electric field strength within the desired range, the height of the transfer channel may therefore be limited in some embodiments to a maximum of about 3.3 mm (10 kV/3 kV/mm).

The width of the transfer channel may be practically limited to a range of at least 0.5 mm to not more than 4 mm. As explained below, an incline adjuster may be constructed of 3 or more layers of thermal plastic urethane film. The layers of film may be bonded together with heat and pressure. During this bonding process, temperatures in portions of the materials may exceed the glass transition temperature when melting so as to bond melted materials of adjoining layers. The pressure during bonding inter-mixes the melted material, but may also extrude a portion of the melted material into the transfer channel preformed within the middle spacer layer of the incline adjuster. The channel may thus be partially filled by this material. At channel widths less than 0.5 mm, the proportion of the material extruded may be a large percentage of the channel width, thereby restricting flow of the ER fluid.

The maximum width of the channel may be limited by the physical space between the two chambers of the incline adjuster. If the channel is wide, the material within the middle layer may become thin and unsupported during construction, and walls of the channel may be easily dislodged. The equivalent series resistance of ER fluid will also decrease as channel width increases, which increases the power consumption. For a shoe size range down to M5.5 (US) the practical width may be limited to less than 4 mm.

The desired length of the transfer channel may be a function of the maximum pressure difference between chambers of the incline adjuster when in use. The longer the channel, the greater the pressure difference that can be withstood. Optimum channel length may be application dependent and construction dependent and therefore may vary among different embodiments. A detriment of a long transfer channel is a greater restriction to fluid flow when the electric field is removed. In some embodiments, practical limits of channel length are in the range of 25 mm to 350 mm.

Incline adjuster **16** includes a medial side fill tab **117** and a lateral side fill tab **118**. Tabs **117** and **118** respectively include fill channels **119** and **120**. After certain components of incline adjuster **116** have been assembled and bonded, and as described below in further detail, ER fluid may be injected into chambers **35** and **36** and into transfer channel **51** through channel **119** and/or through channel **120**. Crimps **125** and **126** may subsequently be formed to close and seal channels **119** and **120**.

In some embodiments, an incline adjuster may have a polymeric housing. As seen in FIG. **4**B, the polymeric housing of incline adjuster **16** may include a bottom layer **53**, a middle/spacer layer **54**, and a top layer **55**. Bottom layer **53** forms the bottoms of chambers **35** and **36**, the bottom of transfer channel **51**, the bottoms of access passages **39** and **40**, and the bottoms of fill channels **119** and **120**. Middle/spacer layer **54** includes open spaces that form the side walls of chambers **35** and **36**, the side walls of transfer channel **51**, the side walls of fill channels **119** and **120**, and the side walls of passages **39** and **40**. Top layer **55** includes two pockets. A medial side pocket **57** forms the top and upper sidewalls of medial chamber **35**. A lateral side pocket **58** forms the top and upper sidewalls of lateral chamber **36**. Other portions of top layer **55** form the top of transfer channel **51**, the tops of fill channels **119** and **120**, and the tops of passages **39** and **40**. A bottom surface of middle layer **54** may be welded or otherwise bonded to a portion of the top surface of bottom layer **53**. A top surface of middle layer **54** may be welded or otherwise bonded to a portion of the bottom surface of top layer **55**.

The construction of incline adjuster **16** is further understood by reference to FIGS. **5**A through **5**D**3**. FIG. **5**A is a top view of bottom layer **53**. Bottom layer **53** includes a flat panel **81** having a top surface **59**. Except for an opening **60** that is part of fulcrum aperture **37**, panel **81** is a continuous sheet. Layer **53** further includes a continuous conductive trace **116** formed on top surface **59**. Trace **116** includes a bottom electrode **61** and an extension **62**. Electrode **61** is positioned to extend over the portion of layer **53** that forms the bottom of transfer channel **51**. As seen in more detail below, electrode **61** follows the path of and coincides with channel **51**. Extension **62** branches away from the path of channel **51** and towards the rear edge of bottom layer **53**. As explained in more detail below, extension **62** provides a location to electrically connect terminal **23***b* (FIG. **3**) to electrode **61**. In some embodiments, conductive trace **116** is a span of conductive ink that has been printed onto surface **59**. The conductive ink used to form conductive trace **116** may be, e.g., an ink that comprises silver microparticles in a polymer matrix that includes thermoplastic polyurethane (TPU), and that bonds with TPU of panel **81** to form a flexible conductive layer. One example of such an ink is PE872 stretchable conductor available from E.I. DuPont De Nemours and Company.

In some embodiments, panel **81** is formed from two separate inner and outer sheets of polymeric material that have been laminated together. The outer sheet may be a 0.4 mm sheet of TPU having a Shore A durometer value of 85. An example of such a material includes a sheet formed from TPU resin having part number A92P4637 and available from Huntsman Corporation. In some embodiments, the outer sheet in panel **81** may be a 0.5 mm sheet of polyester-based TPU having a Shore A durometer value of 85. The inner sheet in panel **81** may be a 0.1 mm thick 2-layer polyurethane/polyurethane sheet in which one of the sheet layers is of higher durometer than the other of those two layers. Examples of such 2-layer of polyurethane/polyurethane sheets are commercially available from Bemis Associates Inc.

In some embodiments, layer **53** may be fabricated in the following manner. Prior to forming panel **81**, conductive trace **116** is screen printed or otherwise applied to the higher durometer face of the inner sheet. The lower durometer face of the inner sheet may then be placed into contact with an inner face of the outer sheet. The inner and outer sheets may then be laminated together by applying heat and pressure. Bottom layer **53** is then cut from the laminated sheets so that conductive trace **116** is in the proper location relative to outer edges and relative to opening **60**.

FIG. **5**B is a top view of middle layer **54** showing top surface **63** of middle layer **54**. Middle layer **54** includes numerous open spaces that extend from top surface **63** to the bottom surface of middle layer **54**. An open space **64** is isolated from other open spaces in layer **54** and is part of fulcrum aperture **37**. Open space **127** forms side walls of medial fluid chamber **35**. Open space **128** forms side walls of lateral fluid chamber **36**. Open space **129** is connected to open spaces **127** and **128** and forms side walls of channel **51**. Open spaces **131** and **132** are respectively connected to open spaces **127** and **128** and respectively form side walls of fill channels **119** and **120**. Open spaces **133** and **134**, which are isolated from each other and from other open spaces in layer **54**, respectively form sides walls of access passages **39** and **40**. In some embodiments, middle layer **54** is cut from a single sheet of TPU that is harder than TPU used in layers **53** and **55**. In some such embodiments, the TPU used for layer **54** is 1.0 mm thick and has a Shore A durometer value of 92. An example of such a material includes a sheet formed from TPU resin having part number A85P44304 and available from Huntsman Corporation. Other examples of material that can be used for layer **54** include 1.0 mm thick TPU having a Shore D durometer value of 72 (e.g., a sheet formed from TPU resin having part number D7101 and available from Argotec, LLC) and 1.0 mm thick TPU having a Shore A durometer value of 87 (e.g., a sheet formed from aromatic polyether-based TPU resin having part number ST-3685-87 and available from Argotec, LLC).

FIG. **5C1** is a top view of top layer **55** showing top surface **52** of top layer **55**. In FIG. **5C1**, pockets **57** and **58** are convex structures. Medial pocket **57** is molded or otherwise formed into the sheet of top layer **55** on the medial side and forms the top and upper sidewalls of medial fluid chamber **35**. Lateral pocket **58** is molded or otherwise formed into the sheet of top layer **55** on the lateral side and forms the top and upper sidewalls of lateral fluid chamber **36**. Layer **55** may be formed from a relatively soft and flexible TPU that allows pockets **57** and **58** to easily collapse and expand so as to allow tops of chambers **35** and **36** to change height as ER fluid moves into and out of chambers **35** and **36**. In at least some embodiments, and as explained below, top layer **55** may formed from a 2-sheet lamination similar to that used for bottom layer **53**.

FIG. **5C2** is a bottom view of top layer **55**. Top layer **55** includes a panel **82** having a bottom surface **68**. In FIG. **5C2**, pockets **57** and **58** are concave structures. Layer **55** further includes a continuous conductive trace **135** formed on bottom surface **68**. Trace **135** includes a top electrode **69** and an extension **70**. Electrode **69** extends over the portion of layer **55** that forms the top of transfer channel **51**. As seen in more detail below, electrode **69** follows the path of and coincides with channel **51**. Extension **70** branches away from the path of channel **51** and towards the rear edge of top layer **55**. As explained in more detail below, extension **70** provides a location for terminal **24***b* to electrically connect to electrode **69**. In some embodiments, conductive trace **135** is a span of conductive ink that has been printed onto surface **68**. The conductive ink used to form conductive trace **135** may be the same type of ink used to form conductive trace **116**. FIG. **5C3**, a partial area cross-sectional view taken from the location indicated in FIG. **5C2**, shows additional details of top electrode **69** and of pocket **58**. Pocket **57** and other portions of top electrode may be similar. Except for an opening **66** that is part of fulcrum aperture **37**, panel **82** is shown in FIG. **5C2** as a continuous sheet. In other embodiments, there may be additional openings or gaps in panel **82** (e.g., between portions of trace **135**).

Panel **82** may comprise laminated inner and outer sheets of the same materials used to create panel **81**. In some embodiments, layer **55** may be fabricated in the following manner. Prior to forming panel **82**, conductive trace **135** is screen printed or otherwise applied to the higher durometer face of the inner sheet. The lower durometer face of the inner sheet may then be placed into contact with an inner face of the outer sheet. The two sheets may then be laminated together by applying heat and pressure. The laminated sheets are then thermoformed using a mold having cavities corresponding to the shapes of pockets **57** and **58**. Care is taken during the thermoforming process to avoid damaging trace **135** and to properly position trace **135** relative to pockets **57** and **58**. Layer **55** is then cut from the laminated and thermoformed sheets so that conductive trace **135** is in the proper location relative to outer edges and relative to opening **66**.

FIG. **5D1** shows a first assembly operation when fabricating incline adjuster **16**. As part of the first assembly operation, a first patch **139** is placed over a portion of conductive trace **116**. In particular, patch **139** spans the width of electrode **61** in the region where branch **62** joins electrode **61**, as well as the portion of branch **62** adjacent to electrode **61**. In some embodiments, and as shown in FIG. **5D1**, patch **139** is wider than branch **62**. Patch **139** may be, e.g., a thin strip of TPU. In some embodiments the 0.1 mm inner sheet material used for panels **81** and **82** may also be used for patch **139**, with the higher durometer side of the material placed toward trace **116**. After placement of patch **139**, middle layer **54** is placed onto bottom layer **53** so that a bottom surface **67** of middle layer **54** is in contact with top surface **59** of panel **81**, and so that patch **139** is interposed between top surface **59** and bottom surface **67**, as well as between portions of trace **116** and bottom surface **67**. In some embodiments, alignment holes (not shown) may be formed in layers **53**, **54**, and **55** to assist in positioning during the operation of FIG. **5D1** and in subsequent assembly operations.

FIG. **5D2** shows a second assembly operation when fabricating incline adjuster **16**. The left side of FIG. **5D2** shows layers **53** and **54** and patch **139** after the assembly operation of FIG. **5D1**. Edges of patch **139** covered by middle layer **54** are indicated with broken lines. Electrode **61** extends over the portion of the layer **53** top surface that forms a bottom of channel **51**. A portion of extension **62** extends over the portion of the layer **53** top surface that forms a bottom of access passage **39**.

In the second assembly operation of FIG. **5D2**, a second patch **140** is placed over a portion of conductive trace **135**. In particular, patch **140** spans the width of electrode **69** in the region where branch **70** joins electrode **69**, as well as the portion of branch **70** adjacent to electrode **69**. In some embodiments, and as shown in FIG. **5D2**, patch **140** is wider than branch **70**. Patch **140** may also be, e.g., a thin strip of TPU. In some embodiments, patch **140** is cut from the same material used for patch **139** and is positioned with the higher durometer face toward trace **135**. After placement of patch **140**, assembled layers **53** and **54** (with interposed patch **139**) are placed onto top layer **55** so that the bottom surface **68** of panel **82** is in contact with top surface **63** of middle layer **54**, and so that patch **140** is interposed between top surface **63** and bottom surface **68**, as well as between portions of trace **135** and top surface **63**.

FIG. **5D3** shows layers **53**, **54**, and **55** after the assembly operation of FIG. **5D2**. The positions of channel **51**, channels **119** and **120**, and passages **39** and **40** are indicated with broken lines. Although not visible in FIG. **5D3**, electrode **69** extends over the portion of the layer **55** bottom surface that forms a top of channel **51**. A portion of extension **70** extends over the portion of the layer **55** bottom surface that forms a top of access passage **40**.

Layers **53**, **54**, and **55** and patches **139** and **140** may be bonded after assembly by RF (radio frequency) welding. In some embodiments, a multi-step RF welding operation is performed. FIGS. **8**A and **8**B are top views of two sides of an RF welding tool used in the first welding operation in some embodiments. FIG. **8**A shows a side **401***a* that contacts the exposed bottom surface of bottom layer **53**. Side **401***a* includes a wall **403***a* that extends outward from a planar base **405***a*. FIG. **8**B shows a side **401***b* that contacts the exposed top surface **52** of top layer **55**. Side **401***b* includes a wall **403***b* that extends outward from a planar base **405***b*. Wall **403***b* has a height above base **405***b* that is greater than the heights of pockets **57** and **58**. As can be appreciated by comparing FIGS. **8**A and **8**B with FIG. **5**D3, walls **403***a* and **403***b* include portions that correspond to the portions of middle layer **54** that define the shape of channel **51**. Walls **403***a* and **403***b* further include portions that correspond to portions of middle layer **54** defining the sides of chambers **35** and **36**, portions that correspond to portions of middle layer **54** defining passages **39** and **40**, portions that correspond to portions of middle layer **54** defining the region between passages **39** and **40** and channel **51**, and portions that correspond to portions of middle layer **54** defining the sides of channels **119** and **120**.

Sides **401***a* and **401***b* may be attached to opposing sides of a fixture that is configured to press sides **401***a* and **401***b* together while RF frequency electrical power is applied to sides **401***a* and **401***b*. During the first RF welding operation, the assembly of FIG. **5**D3 is placed between sides **401***a* and **401***b*, with side **401***a* contacting the bottom surface of layer **53** and side **401***b* contacting the top surface of layer **55**, and with edges of walls **403***a* and **403***b* aligned with their corresponding portions of middle layer **54**. In some embodiments, sides **401***a* and **401***b* are pressed together against the assembly (during application of electrical power) so as to compress regions of the assembly between the tops of walls **403***a* and **403***b* to a thickness at the end of the first RF welding operation that is 85% of the thickness prior to the first RF welding operation.

Subsequently, the assembly of FIG. **5D3** is subjected to a second RF welding operation. FIGS. **8**C and **8**D are top views of two sides of an RF welding tool used in the second welding operation in some embodiments. FIG. **8**C shows a side **402***a* that contacts the exposed bottom surface of bottom layer **53**. Side **402***a* includes a wall **404***a* that extends outward from a planar base **406***a*. FIG. **8**B shows a side **402***b* that contacts the exposed top surface **52** of top layer **55**. Side **402***b* includes a wall **404***b* that extends outward from a planar base **406***b*. Wall **404***b* has a height above base **406***b* that is greater than the heights of pockets **57** and **58**. As can be appreciated by comparing FIGS. **8**C and **8**D with FIG. **5**D3, walls **404***a* and **404***b* include portions that correspond to the portions of middle layer **54** that define the edges of chambers **35** and **36**.

In the second RF welding operation, the assembly of FIG. **5**D3 is placed between sides **402***a* and **402***b*, with side **402***a* contacting the bottom surface of layer **53** and side **402***b* contacting the top surface of layer **55**, and with edges of walls **404***a* and **404***b* aligned with their corresponding portions of middle layer **54**. In some embodiments, sides **402***a* and **402***b* are pressed together against the assembly (during application of electrical power) so as to compress regions of the assembly between the tops of walls **404***a* and **404***b* to a thickness at the end of the second RF welding operation that is 65% of the thickness at the start of the second RF welding operation.

In some embodiments, an intermediate RF welding operation may be performed between the first and second welding operations. In some such embodiments, tubes are inserted into the rear ends of channels **119** and **120**. Those tubes are then sealed in place by applying sides of an RF welding tool around the rear ends of tabs **117** and **118**. Those tubes and the portions of tabs **117** and **118** welded to those tubes may then be cut away after incline adjuster **16** is filled with ER fluid.

As previously indicated, incline adjuster **16** is configured for installation in a right shoe of a pair. An incline adjuster configured for installation in a left shoe of that pair may be a mirror image of incline adjuster **16**. Accordingly, sides of RF welding tools used to fabricate that left shoe incline adjuster may be mirror images of the tool sides shown in FIGS. **8**A through **8**D.

Additional details of the regions of incline adjuster **16** that include patches **139** and **140** can be found in the U.S. provisional patent application 62/260,883 titled "Electrorheological Fluid Structure Having Strain Relief Element and Method of Fabrication", which application was filed on the same date as the present application and is incorporated by reference herein.

At the conclusion of the RF welding operations to bond layers **53**, **54**, and **55** and interposed patches **139** and **140**, terminals **23***b* and **24***b* may be attached to portions of extensions **62** and **70** exposed in access passages **39** and **40**. In some embodiments, terminals **23***b* and **24***b* are attached, and wires **23***a* and **24***a* RF welded in place, as described in the U.S. provisional patent application 62/260,890 titled "Electrorheological Fluid Structure With Attached Conductor and Method of Fabrication", which application was filed on the same date as the present application and is incorporated by reference herein.

After attachment of wires **23***a* and **23***b*, the housing of incline adjuster **16** formed by bonding of layers **53**, **54**, and **55** may be filled with ER fluid. FIG. **9** is a block diagram showing steps in a method of filling the incline adjuster **16** housing according to some embodiments. FIGS. **10**A through **10**K are partially schematic drawings showing operations associated with various steps in a method according to FIG. **9**.

In step **501**, ER fluid is introduced into the interior volume of housing **169** of incline adjuster **16**. Housing **169** comprises bonded layers **53**, **54**, and **55** and patches **139** and **140**. In some embodiments, and as shown in FIG. **10**A, step **501** may include inserting a needle of a syringe **171** through fill channel **120** and into lateral fluid chamber **36**. ER fluid is then injected. Fill channel **119** is left open so that air may escape as ER fluid fills chamber **36**, transfer channel **51** and medial fluid chamber **35**. FIG. **10**B shows additional details of the filling operation. In FIG. **10**B, a portion of top layer **55** has been removed to expose middle layer **54**. For convenience, bottom electrode **61** and patches **139** and **140** are omitted from FIG. **10**B. As the level of ER fluid **121** in chamber **36** rises, ER fluid **121** eventually flows into channel **51** and then into chamber **35**. At the conclusion of step **501**, and as shown in FIG. 10C, chambers **36** and **35** and channel **51** are filled with ER fluid **121**. ER fluid **121** also fills channels **119** and **120** to the levels indicated with arrows.

In step **503**, filled housing **169** is placed into a vacuum chamber. FIG. 10D schematically shows housing **169** inside a vacuum chamber **172** while the interior of chamber **172** is at atmospheric pressure P_A. Atmospheric pressure P_A is the ambient air pressure and is, depending on geographic location, approximately 1 bar (14.7 psia). Subsequently, and as shown in FIG. 10E, chamber **172** is closed and a vacuum pump is activated. Air is withdrawn, thereby creating a sub-atmospheric pressure P_{SA} within chamber **172**. Sub-atmospheric pressure P_{SA} is less than atmospheric pressure P_A. In some embodiments, sub-atmospheric pressure P_{SA} is 10^{-3} (0.001) millibar or lower. In other embodiments, sub-atmospheric pressure P_{SA} may have a different value. Examples of different values for sub-atmospheric pressure P_{SA} in other embodiments include, without limitation, 2×10^{-3} (0.002) millibar or lower, 3×10^{-3} (0.003) millibar or lower, 4×10^{-3} (0.004) millibar or lower, 5×10^{-3} (0.005) millibar or lower, 6×10^{-3} (0.006) millibar or lower, 7×10^{-3} (0.007) millibar or lower, 8×10^{-3} (0.008) millibar or lower, and 9×10^{-3} (0.009) millibar or lower. In some embodiments, sub-atmospheric pressure P_{SA} may fluctuate within a range during step **503** and/or during step **507** (described below). For example, sub-atmospheric pressure P_{SA} may in some embodiments vary between 10^{-3} (0.001) millibar and 10^{-2} (0.01) millibar.

When ER fluid **121** inside housing **169** is exposed to sub-atmospheric pressure P_{SA}, and as also shown in FIG. 10E, air within ER fluid **121** comes out of solution and forms bubbles. As part of step **503**, housing **169** remains at sub-atmospheric pressure P_{SA} for a period of time. During this time, air bubbles in fluid chambers **35** and **36** collect and rise, ultimately escaping through channels **119** and **120**. As a result, the level of ER fluid **121** in channels **119** and **120** drops. Arrows included in FIG. 10F indicate the dropped levels of ER fluid **121** in channels **119** and **120**. In some embodiments, housing **503** remains at sub-atmospheric pressure P_{SA} until it is visually determined that bubbles are no longer coming out of solution.

As further shown in FIG. 10F, air bubbles that formed in transfer channel **51** have also risen and collected. This results in formation of air pockets **173** in the channel bends that, in the current orientation of housing **169**, form the highest points in channel **51**.

Subsequently, the air pressure in vacuum chamber **172** is returned to atmospheric pressure P_A and housing **169** is removed from chamber **172**. In step **505**, and as shown in FIG. 10G, the needle of syringe **171** is reinserted into channel **120**. A small amount of additional ER fluid **121** is introduced into chamber **36**. This introduction of additional ER fluid **121** pushes the ER fluid already in chamber **36** into channel **51**. In turn, this pushes air bubbles **173** along channel **51** and into chamber **35**. Once in chamber **35**, those air bubbles can escape through channel **119**.

In step **505**, only a small amount of additional ER fluid **121** is added. Thus, only ER fluid **121** in chamber **36** from which air was previously removed (in step **503**) is pushed into channel **51**. This prevents additional air pockets from forming in channel **51**.

In step **507**, housing **169** is returned to vacuum chamber **172**. Chamber **172** is closed and a vacuum pump activated, again reducing the pressure inside chamber **172** and exposing ER fluid **121** in housing **169** to sub-atmospheric pressure P_{SA}. As shown in FIG. 10H, this causes air bubbles to form in the additional ER fluid **121** added to chamber **36** in step **505**. Housing **169** is maintained at sub-atmospheric pressure P_{SA} for a period of time (e.g., until it is visually determined that bubbles are no longer coming out of solution). During that time, the air bubbles in chamber **36** collect and rise, ultimately escaping through channel **120**.

FIG. 10I shows housing **169** after removal from vacuum chamber **172** at the end of step **507**. ER fluid **121** in chamber **169** has been purged of air, and extends into channels **119** and **120** to levels indicated by arrows. Removal of air from ER fluid **121** will help to prevent malfunctioning of incline adjuster **16** during operation. In particular, the electrical field strength needed to arc across an air gap is approximately 3 kV/mm. This may be lower than the field strength needed to achieve sufficient viscosity increase in ER fluid **121** in channel **51**. If air bubbles are present in channel **51** when an electrical field stronger that 3 kV/mm is imposed across electrodes **61** and **69**, current may arc through those bubbles and result in collapse of the electrical field.

In step **509**, channels **119** and **120** are sealed. The operation of step **509** is shown in FIG. 10J. Sides **175** and **176** of an RF welding tool are pressed across portions of channels **119** and **120** on the top surface of housing **169**. Simultaneously, corresponding sides (not shown) of that RF welding tool are pressed across those same portions of channels **119** and **120** on the bottom surface of housing **169**, and while electrical power is applied. As shown in FIG. 10J, the portions of channels **119** and **120** across which RF welding is performed are below the levels of ER fluid **121** in channels **119** and **120**. Surprisingly, RF welding can be performed directly across a channel that contains ER fluid.

FIG. 10K shows completed incline adjuster **16** that results at the end of step **509**. Subsequently, incline adjuster **16** may be incorporated into a sole structure, and that sole structure incorporated into a shoe.

In some embodiments, an incline adjuster may be modified to improve air removal. FIG. 11A shows an incline adjuster **716** according to one such embodiment. Except as described below, incline adjuster **716** is the same as incline adjuster **16** and can be fabricated in the same way (and using the same materials) as incline adjuster **16**. Incline adjuster **716** differs from incline adjuster **16** with regard to the shapes of the rear portions of lateral fluid chamber **736** and medial fluid chamber **735**. In particular, the rear portions of chambers **735** and **736** have more pronounced concave shapes that peak where connected to channels **719** and **720**. This is shown in further detail in FIG. 11B, a top view of a middle layer **754** of incline adjuster **716**. As seen in FIG. 11B, each of chamber **735** and chamber **736** has a rear region profile that smoothly progresses toward a connection to fill channel **719** or fill channel **720**, and that does not include indentations or other regions where air bubbles might collect. The shapes of cavities **735** and **736** allow air to more easily escape through channels **719** and **720** during steps **503** and **507** of the method of FIG. 9.

FIG. 6 is a block diagram showing electrical system components of shoe **10**. Individual lines to or from blocks in FIG. 6 represent signal (e.g., data and/or power) flow paths and are not necessarily intended to represent individual conductors. Battery pack **13** includes a rechargeable lithium ion battery **101**, a battery connector **102**, and a lithium ion battery protection IC (integrated circuit) **103**. Protection IC **103** detects abnormal charging and discharging conditions, controls charging of battery **101**, and performs other conventional battery protection circuit operations. Battery pack **13** also includes a USB (universal serial bus) port **104** for communication with controller **47** and for charging battery **101**. A power path control unit **105** controls whether power is supplied to controller **47** from USB port **104** or from battery **101**. A Reset button **106** activates or deactivates controller **47** and battery pack **13**. An LED (light emitting diode) **107** indicates whether the controller is ON and the state of the electrical field. The above-described individual elements of battery pack **13** may be conventional and commercially available components that are combined and used in the novel and inventive ways described herein.

Controller **47** includes the components housed on PCB **46**, as well as converter **45**. In other embodiments, the components of PCB **46** and converter **45** may be included on a single PCB, or may be packaged in some other manner. Controller **47** includes a processor **110**, a memory **111**, an inertial measurement unit (IMU) **113**, and a low energy wireless communication module **112** (e.g., a BLUETOOTH communication module). Memory **111** stores instructions that may be executed by processor **110** and may store other data. Processor **110** executes instructions stored by memory **111** and/or stored in processor **110**, which execution results in controller **47** performing operations such as are described herein and in U.S. patent application Ser. No. 14/725,218, titled "Footwear Including an Incline Adjuster" and filed May 29, 2015, which application (in its entirety) is incorporated by reference herein. As used herein, instructions may include hard-coded instructions and/or programmable instructions.

IMU **113** may include a gyroscope and an accelerometer and/or a magnetometer. Data output by IMU **113** may be used by processor **110** to detect changes in orientation and motion of shoe **10**, and thus of a foot wearing shoe **10**. As explained in more detail below, processor **10** may use such information to determine when an incline of a portion of shoe **10** should change. Wireless communication module **112** may include an ASIC (application specific integrated circuit) and be used to communicate programming and other instructions to processor **110**, as well as to download data that may be stored by memory **111** or processor **110**.

Controller **47** includes a low-dropout voltage regulator (LDO) **114** and a boost regulator/converter **115**. LDO **114** receives power from battery pack **13** and outputs a constant voltage to processor **110**, memory **111**, wireless communication module **112**, and IMU **113**. Boost regulator/converter **115** boosts a voltage from battery pack **13** to a level (e.g., 5 volts) that provides an acceptable input voltage to converter **45**. Converter **45** then increases that voltage to a much higher level (e.g., 5000 volts) and supplies that high voltage across electrodes **61** and **69** of incline adjuster **16**. Boost regulator/converter **115** and converter **45** are enabled and disabled by signals from processor **110**. Controller **47** further receives signals from medial FSR **31** and from lateral FSR **32**. Based on those signals from FSRs **31** and **32**, processor **110** determines whether forces from a wearer foot on medial fluid chamber **35** and on lateral fluid chamber **36** are creating a pressure within chamber **35** that is higher than a pressure within chamber **36**, or vice versa.

The above-described individual elements of controller **47** may be conventional and commercially available components that are combined and used in the novel and inventive ways described herein. Moreover, controller **47** is physically configured, by instructions stored in memory **111** and/or processor **110**, to perform the herein described novel and inventive operations in connection with controlling transfer of fluid between chambers **35** and **36** so as to adjust the incline of the forefoot portion of the shoe **10** footbed **14**.

FIGS. **7**A through **7**D are partially schematic area cross-sectional diagrams showing operation of incline adjuster **16**, according to some embodiments, when going from a minimum incline condition to a maximum incline condition. In the minimum incline condition, an incline angle α of the top plate relative to the bottom plate has a value of α_{min} representing a minimum amount of incline sole structure **12** is configured to provide in the forefoot region. In some embodiments, α_{min}=0°. In the maximum incline condition, the incline angle α has a value of α_{max} representing a maximum amount of incline sole structure **12** is configured to provide. In some embodiments, α_{max} is at least 5°. In some embodiments, α_{max}=10°. In some embodiments, α_{max} may be greater than 10°.

In FIGS. **7**A-**7**D, bottom plate **29**, incline adjuster **16**, top plate **41**, FSR **31**, FSR **32**, and fulcrum element **34** are represented, but other elements are omitted for simplicity. FIG. **7**E is a top view of incline adjuster **16** (in a minimum incline condition) and bottom plate **29** showing the approximate locations of the sectioning lines corresponding to the views of FIGS. **7**A-**7**D. Top plate **41** is omitted from FIG. **7**E, but the peripheral edge of top plate **41** would generally coincide with that of bottom plate **29** if top plate **41** were included In FIG. **7**E. Although fulcrum element **34** would not appear in an area cross-section according to the section lines of FIG. **7**E, the general position of fulcrum element **34** relative to the medial and lateral sides of other elements in FIGS. **7**A-**7**D is indicated with broken lines.

Also indicated in FIGS. **7**A through **7**D are a lateral side stop **123** and a medial side stop **122**. Medial side stop **122** supports the medial side of top plate **41** when incline adjuster **16** and top plate **41** are in the maximum incline condition. Lateral side stop **123** supports the lateral side of top plate **41** when incline adjuster **16** and top plate **41** are in the minimum incline condition. Lateral side stop **123** prevents top plate **41** from tilting toward the lateral side. Because runners proceed around a track in a counterclockwise direction during a race, a wearer of shoe **10** will be turning to his or her left when running on curved portions of a track. In such a usage scenario, there would be no need to incline the footbed of a right shoe sole structure toward the lateral side. In other embodiments, however, a sole structure may be tiltable to either medial or lateral side.

In some embodiments, a left shoe from a pair that includes shoe **10** may be configured in a slightly different manner from what is shown in FIGS. **7**A-**7**D. For example, a medial side stop may be at a height similar to that of lateral side stop **123** of shoe **10**, and a lateral side stop may be at a height similar to that of medial side stop **122** of shoe **10**. In such embodiments, the top plate of the left shoe moves between a minimum incline condition and maximum incline condition in which the top plate is inclined to the lateral side.

The locations of lateral side stop **123** and of medial side stop **122** are represented schematically in FIGS. **7**A-**7**D, and are not shown in previous drawing figures. In some embodiments, lateral side stop **123** may be formed as a rim on the lateral side or edge of bottom plate **29**. Similarly, medial side stop **122** my be formed as a rim on the medial side or edge of bottom plate **29**.

FIG. **7**A shows incline adjuster **16** when top plate **41** is in a minimum incline condition. Shoe **10** may be configured to place top plate **41** into the minimum incline condition when a wearer of shoe **10** is standing or is in starting blocks about to begin a race, or when the wearer is running a straight portion of a track. In FIG. **7**A, controller **47** is maintaining the voltage across electrodes **61** and **69** at one or more flow-inhibiting voltage levels ($V=V_{fi}$). In particular, the voltage across electrodes **61** and **69** is high enough to generate an electrical field having a strength sufficient to increase the viscosity of ER fluid **121** in transfer channel **51** to a viscosity level that prevents flow out of or into chambers **35** and **36**. In some embodiments, a flow-inhibiting voltage level V_{fi} is a voltage sufficient to create a field strength between electrodes **61** and **69** of between 3 kV/mm and 6 kV/mm. In FIGS. **7**A through **7**D, light stippling is used to indicate ER fluid **121** having a viscosity that is at a normal viscosity level, i.e., unaffected by an electrical field. Dense stippling is used to indicate ER fluid **121** in which the viscosity has been raised to a level that blocks flow through channel **51**. Because ER fluid **121** cannot flow through channel **51** under the conditions shown in FIG. **7**A, the incline angle α of top plate **41** does not change if the wearer of shoe **10** shifts weight between medial and lateral sides of shoe **10**.

FIG. **7**B shows incline adjuster **16** soon after controller **47** has determined that top plate **41** should be placed into the maximum incline condition, i.e., inclined to $\alpha=\alpha_{max}$. In some embodiments, controller **47** makes such a determination based on a number of steps taken by the shoe **10** wearer. Upon determining that top plate **41** should be inclined to α_{max}, controller **47** determines if the foot wearing shoe **10** is in a portion of the wearer gait cycle in which shoe **10** is in contact with the ground. Controller **47** also determines if a difference ΔP_{M-L} between the pressure P_M of ER fluid **121** in medial side chamber **35** and the pressure P_L of ER fluid **121** in lateral side chamber **36** is positive, i.e., if P_M-P_L is greater than zero. If shoe **10** is in contact with the ground and ΔP_{M-L} is positive, controller **47** reduces the voltage across electrodes **61** and **69** to a flow-enabling voltage level V_{fe}. In particular, the voltage across electrodes **61** and **69** is reduced to a level that is low enough to reduce the strength of the electrical field in transfer channel **51** so that the viscosity of ER fluid **121** in transfer channel **51** is at a normal viscosity level.

Upon reducing the voltage across electrodes **61** and **69** to a V_{fe} level, the viscosity of ER fluid **121** in channel **51** drops. ER fluid **121** then begins flowing out of chamber **35** and into chamber **36**. This allows the medial side of top plate **41** to begin moving toward bottom plate **29**, and the lateral side of top plate **41** to begin moving away from bottom plate **29**. As a result, the incline angle α begins to increase from α_{min}.

In some embodiments, controller **47** determines if shoe **10** is in a step portion of the gait cycle and in contact with the ground based on data from IMU **113**. In particular, IMU **113** may include a three-axis accelerometer and a three-axis gyroscope. Using data from the accelerometer and gyroscope, and based on known biomechanics of a runner foot, e.g., rotations and accelerations in various directions during different portions of a gait cycle, controller **47** can determine whether the right foot of the shoe **10** wearer is stepping on the ground. Controller **47** may determine if ΔP_{M-L} is positive based on the signals from FSR **31** and FSR **32**. Each of those signals corresponds to magnitude of a force from a wearer foot pressing down on the FSR. Based on the magnitudes of those forces and on the known dimensions of chambers **35** and **36**, controller **47** can correlate the values of signals from FSR **31** and FSR **32** to a magnitude and a sign of ΔP_{M-L}.

FIG. **7**C shows incline adjuster **16** very soon after the time associated with FIG. **7**B. In FIG. **7**C, top plate **41** has reach the maximum incline condition. In particular, the incline angle α of top plate **41** has reached α_{max}. Medial stop **122** prevents incline angle α from exceeding α_{max}. FIG. **7**D shows incline adjuster **16** very soon after the time associated with FIG. **7**C. In FIG. **7**D, controller **47** has raised the voltage across electrodes **61** and **69** to a flow-inhibiting voltage level V_{fi}. This prevents further flow through transfer channel **51** and holds top plate **41** in the maximum incline condition. During a normal gait cycle, downward force of a right foot on a shoe is initially higher on the lateral side as the forefoot rolls to the medial side. If flow through channel **51** were not prevented, the initial downward force on the lateral side of the wearer right foot would decrease incline angle α.

In some embodiments, a shoe may include an incline adjuster and other components that are configured to incline a different portion of a shoe footbed. As but one example, a basketball shoe may include an incline adjuster similar to incline adjuster **16**, but having one chamber positioned in a medial midfoot or heel region, and another chamber positioned in a lateral midfoot or heel region, and with shapes of the chambers modified to match those positions. A controller of such a shoe could be configured to perform operations similar to those described above upon determining that a wearer's body position corresponds to a need to incline the midfoot and/or heel, and upon determining that such inclination is no longer needed. When cutting to the left, for example, a right shoe having a midfoot and heel region inclined medially could provide additional support and stability. A controller could be configured to determine that a cutting motion is occurring based on position and/or movement of the wearer's torso, and/or based on a sudden increase in pressure on a medial side of the shoe, and/or based on sensors located within an upper that indicate the heel region has tilted relative to the forefoot region.

A controller need not be located within a sole structure. In some embodiments, for example, some or all components of a controller could be located with the housing of a battery assembly such as battery assembly **13** and/or in another housing positioned on a footwear upper.

As can be appreciated from the above, incline adjuster **16** is a structure holding an ER fluid. Other embodiments include other structures that hold or that are configured to hold ER fluid and that have features similar to those described in connection with incline adjuster **16**, but that may differ from incline adjuster **16** in one or more respects. Such structures, referred to herein as ER fluid structures for convenience, may be used in foot wear or in other applications.

In some embodiments, an ER fluid structure may include chambers having sizes and/or shapes different from those shown in above. Similarly, a transfer channel may have other sizes and/or shapes.

In some embodiments, an ER fluid structure may only have a single chamber, with one end of a transfer channel left open. That open transfer channel may subsequently be connected to another structure having an ER fluid reservoir or chamber, to a pump configured to transfer ER fluid from a separate reservoir or chamber, or to some other component.

In some embodiments, and ER fluid structure may not include chambers. For example, such a structure could be similar to the central portion of incline adjuster **16** that includes transfer channel **51** and access passages **39** and **40**. Instead of connecting to chambers within the structure, however, the transfer channel ends may be open and connectable to separate components. Such a structure could be used, e.g., as a valve in an ER fluid system.

The foregoing description of embodiments has been presented for purposes of illustration and description. The foregoing description is not intended to be exhaustive or to limit embodiments of the present invention to the precise form disclosed, and modifications and variations are possible in light of the above teachings or may be acquired from practice of various embodiments. The embodiments discussed herein were chosen and described in order to explain the principles and the nature of various embodiments and their practical application to enable one skilled in the art to utilize the present invention in various embodiments and with various modifications as are suited to the particular use contemplated. Any and all combinations, subcombinations and permutations of features from herein-described embodiments are the within the scope of the invention. In the claims, a reference to a potential or intended wearer or a user of a component does not require actual wearing or using of the component or the presence of the wearer or user as part of the claimed invention.

The invention claimed is:

1. A method comprising:

introducing electrorheological fluid into an interior volume of a housing through a first channel connecting the interior volume with an exterior of the housing, while allowing air to exit through a second channel connecting the interior volume with the exterior of the housing, until the electrorheological fluid at least partially fills the first channel and the second channel, wherein the interior volume comprises first and second chambers connected by a serpentine third channel, wherein the first channel extends into the first chamber, and wherein the second channel extends into the second chamber;

subjecting the electrorheological fluid within the housing to a sub-atmospheric pressure;

removing the housing from a vacuum chamber;

while the housing is removed from the vacuum chamber, and while one of the first and second channels remains open, injecting additional electrorheological fluid into the housing through the other of the first and second channels;

after injecting the additional electrorheological fluid into the housing, returning the housing to the vacuum chamber;

after returning the housing to the vacuum chamber, again subjecting the electrorheological fluid within the housing to a sub-atmospheric pressure; and

sealing the interior volume relative to an exterior of the housing.

2. The method of claim **1**, wherein the housing is a polymeric housing.

3. The method of claim **1**, wherein the housing comprises an electrode coinciding with at least a portion of the third channel.

4. The method of claim **1**, wherein the housing comprises first and second electrodes, each of the first and second electrodes coinciding with at least a portion of the third channel, and wherein the first and second electrodes are not in electrical contact with one another.

5. The method of claim **1**, wherein the sealing comprises welding across a portion of the first channel containing a portion of the electrorheological fluid.

6. The method of claim **1**, wherein the sealing comprises welding across a portion of the first channel containing a portion of the electrorheological fluid and welding across a portion of the second channel containing a portion of the electrorheological fluid.

7. The method of claim **1**, wherein subjecting the electrorheological fluid within the housing to a sub-atmospheric pressure comprises subjecting the electrorheological fluid to a pressure less than a pressure at which the introducing step was performed.

8. The method of claim **1**, wherein subjecting the electrorheological fluid within the housing to a sub-atmospheric pressure comprises subjecting the electrorheological fluid to a vacuum of 10^{-3} millibar or lower.

9. The method of claim **1**, wherein subjecting the electrorheological fluid within the housing to a sub-atmospheric pressure comprises subjecting the electrorheological fluid to the sub-atmospheric pressure during multiple intervals.

10. The method of claim **1**, wherein the first channel extends through a first fill tab, wherein the second channel extends through a second fill tab, and wherein sealing the interior volume relative to the exterior of the housing comprises:

radio frequency welding across a portion of the first channel, in the first fill tab, containing a portion of the electrorheological fluid; and

radio frequency welding across a portion of the second channel, in the second fill tab, containing a portion of the electrorheological fluid.

11. The method of claim **1**, wherein the serpentine third channel comprises three 180° curved sections joining other sections of the third channel that cover a space between the first and second chambers.

12. The method of claim **1**, wherein an interior of the first chamber comprises a concave shape that peaks where the first channel connects to the first chamber, and wherein an interior of the second chamber comprises a concave shape that peaks where the second channel connects to the second chamber.

* * * * *